SOUTH AFRICAN CONTROLLED ATMOSPHERE STORAGE OPERATOR'S MANUAL

Revised by

Piet van Bodegom[1]

Assisted by

Richard Hurndall[2] , J. A. van der Merwe[3] and Andrew Perks[4]

[1]*Piet van Bodegom cc*, P O Box 85, Elgin. 7180

[2] *Hortgro Science*, P O Box 12789, Boord. 7613

[3]*ARC Infruitec-Nietvoorbij,* Agricultural Research Council

Private bag X5026, Stellenbosch. 7599

[4]*A Perks Enterprises*, 23 Walnut Close, Durbanville Meadows, 7550

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Authors: ***J.S. Findlay***

J.C Combrink

NOTE FROM THE EDITORS

The original manual was compiled and edited by John Findlay and Johan Combrink in 1992. The names of the original contributors can be seen on the following page. Richard Hurndall (from the then DFPT, now HORTGRO) and Kobus van der Merwe (ARC) updated the manual in 2005. The latest 2013 version was updated by Piet van Bodegom (Piet van Bodegom cc), and was assisted by Richard Hurndall (HORTGRO Science) and Kobus van der Merwe (ARC).

This manual is intended as a reference manual for CA store operators who want to learn more about CA storage and those who want to improve the standard of their CA operation. It is the end-product of many hours of discussion and dedication by a lot of people over a number of years. We would like to thank all those who contributed information and material.

Finally, we wish to dedicate this manual to the memory of the late Lossie Ginsburg, a great pioneer in CA storage research in South Africa, and renowned and respected world-wide.

Any correspondence related to the manual can be directed to info@hortgro.co.za.

DISCLAIMER

The intention of this manual is for the education of CA storage operators in the industry and has been compiled with the best collective industry knowledge available. No liability and/or accountability can be accepted for losses incurred due to its use by the editors, the contributors, their respective organisations, as well as HORTGRO and SAAPPA.

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EDITORS

CONTRIBUTORS

Van Bodegom P C; P O Box 85, Elgin 7180
E-mail: pietvb@mweb.co.za

Lategan, H; Safenet (Africa), P O Box 1144, Sanlamhof 7532
E-mail: admin@safenetafrica.co.za

LIST OF ORIGINAL CONTRIBUTORS

Bayliss W

Combrink J C (Dr)

Conradie P

Cunningham D H

Da Silva N

Eksteen G J (Dr)

Findlay J S

Graham D

Henning B

Hurndall R F

Moodie D H D

Schultz A C

Shepherd P

Steynor P

Truter AB

Van Bodegom P C

Drawings by:

Worthington-Smith & Brouwer

J S Findlay, Graymead Farm

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HISTORY CA STORAGE

A. WORLD-WIDE

Dr J. C. Combrink

The idea to modify the atmosphere in which commodities are stored dates back to 1821 when Jacques Bèrard read a paper before the Acadèmie des Sciences in France on alteration of fruit respiration by altering the composition of the atmosphere surrounding them (5). This was the germ of controlled atmosphere, but Bèrard's work was forgotten. In 1897, an Italian, Michelangelo Borelli, suggested the use of *gas mixtures* as a means of storing fresh fruits and in 1899 a patent was granted to a Spaniard, Manuel Belmonte, for storing grapes in carbon dioxide. Experiments with various gases were carried out in the United States by Thatcher and Booth (1903), Fulton (1907), Hill (1913) as well as at the University of Pavia (1928) and the Institute for Agricultural Chemistry in Turin.

The real breakthrough in controlled atmosphere (CA) storage came when Franklyn Kidd and Cyril West started their experiments in 1918 in England. They investigated the possibility of storing apples without refrigeration in artificially generated gas mixtures (3). Their experiments failed and they then investigated low temperature storage. However, all the cultivars they studied developed low temperature injury. They proved subsequently that apples can be stored successfully in gas-tight containers. Oxygen (O_2) is depleted and the carbon dioxide (CO) content increases as a result of natural respiration.

Before 1939, research on CA storage of apples and pears was carried out in the USA, Canada, Australia, South Africa and Denmark. It was found that limiting the rise of CO_2, was beneficial to fruit quality and this led to the development of equipment in the 1930's which removed CO_2 from the atmosphere. These *scrubbers* consisted of chemicals which absorbed the CO_2, first soda ash (sodium hydroxide) and later lime (calcium hydroxide) as well as a suspension of lime in water, ethanolamine, bicarbonate of soda and activated charcoal (5).

A further development was the use of generators which produced a suitable atmosphere through combustion. The first generator was probably devised by Lawton in 1901. He replaced the air in the store by combustion gases, but his invention was never commercialised due to the presence of carbon monoxide in these gases. In 1915, Kapadia modified this system and made significant progress with storage of Australian apples. Atmosphere generators such as *Tectrol* and *Arcagen* became widely used in the USA. Marcellin created controlled atmospheres by circulating air from the storage atmosphere through bags with different permeability for CO_2 and O_2.

The first commercial CA store with a capacity of about 30 ton was built near Canterbury, Kent, in 1929. Before the Second World War, CA storage was mostly practised in the United Kingdom. The first CA stores outside the United Kingdom were the two stores built in South Africa by Molteno Bros in 1934 and 1936. A third was built in 1938. It was impossible to make these rooms gas-tight and they were never used as CA stores. However, they were subsequently sealed and used as CA stores.

In 1938 the Netherlands had one 100 ton chamber. In the USA, CA storage was used commercially for the first time in 1942 in the Hudson Valley for the storage of McIntosh apples (1). Application of CA storage steadily increased world-wide (4) and in some countries more than 50% of the apple and pear crop is stored in CA rooms (5). In South Africa, fruit growers were not particularly interested in this storage technique (2). During the sixties interest was revived, but it was not until 1978 that growers really became interested. In 1979, a delegation comprising growers, cold store operators and scientists visited CA storage facilities in Europe, Israel, UK and the USA. They returned with a vast amount of information and the latest technology which helped considerably to rapidly establish CA storage as a viable enterprise in South Africa. Between 1978 and 1983, the CA storage capacity in South Africa increased by 733% and maintained an average growth rate of more than 35% per annum from 1984 to 1992.

Early research concentrated on establishing optimum conditions for storing different apple and pear cultivars (1). The concentrations of CO_2 and O_2 used initially were high. O_2 concentrations varied between 2,5% and 16% and CO_2 concentrations between 5% and 10%. Gradually these concentrations were lowered as more data on the effect of CA storage on fruit quality was obtained. Automatic control of gas concentrations also made it possible to establish and maintain very low concentrations of O_2 and CO_2.

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HISTORY OF CA STORAGE

B. SOUTH AFRICA

D. H. D. Moodie, D. H. Cunningham, J. A. van der Merwe

The first CA stores were built in South Africa by Molteno Bros in 1934 near the Elgin station under the supervision of E. Griffiths, an electrical and mechanical engineer from Cambridge.

This was a 7-room complex, each room holding ±6 000 lugs of fruit. The building consisted of a steel shell, supported by lattice girders, built by Consani Engineering with soap foam cement blocks as insulation on the inside. The refrigeration was supplied by ceiling mounted ammonia-cooled coils with all cooling of fruit done by air convection and conduction. There were no fans for air circulation.

This complex was subsequently enlarged to 21 rooms, holding a total of 127 000 lugs of apples, thereby becoming one of the largest CA installations in the world at that time. A quantity of lime was put into the room to control some of the CO_2, but the CO_2 was mainly controlled by a portable scrubber. This consisted of a 500 gallon discarded fuel tank (probably underground petrol) on wheels containing caustic soda. The CO_2 laden air from each room was sucked through the tank and was in fact quite an effective scrubber, being able to maintain the CO_2 concentration at around 5%.

In 1936, the Elgin Fruit Company (now the Elgin Fruit Packers Cooperative) owned by Messrs Blackburn, Cunningham and Thomas, built a similar 4-room complex, each room sized for 10 000 wooden lug boxes. They were also cooled by an upright bank of ammonia coils under which was a drip tray and, having no fans, depended on convection only for fruit cooling. This building was constructed from second-hand metal from the Hangklip Whaling Station with foam cement bricks as insulation. Unfortunately, none of the stores were completely gas-tight and used to operate at a temperature of 38°F (3,3°C), 8% O_2 and ± 5% CO_2. Mr Fausto Alberti, who ran the CA stores for Molteno Bros during the 1940's and 50's, said that these stores were far from trouble-free and he used to get extremely breathless when he went inside to change the lime, examine the fruit and inspect the ammonia coils. The caustic soda in the lime scrubber also did a fair amount of damage to the operator's overalls.

Ohenimuri and Winter Pearmain were the two main apple varieties stored in these stores. It was possible to keep the Ohenimuri's in a fairly satisfactory condition until August, whilst the Winter Pearmain could be taken through to September. There was, unfortunately, a large amount of rot in the fruit, up to 30%, but this storage technique made it possible to spread the fruit sales as the local market only came into being during the 1940's.

With the significant advancement in technology in RA (Regular Atmosphere) storage in South Africa during the late 1950's and 60's, at first using central ducts to circulate the air and then later false ceilings, there was a great improvement in the outturn of fruit from RA storage, and CA storage consequently took a back seat.

The input from the cold storage section of the former FFTRI (now ARC Infruitec-Nietvoorbij) under the able leadership of Mr Lossie Ginsburg went a long way to assist producers to store fruit correctly under RA conditions. This made it possible to keep Golden Delicious and red varieties until September/October and Granny Smith until November. It was only in the late 1970's that producers realised there was a market for apples and pears in December and January in spite of the competition from early stone fruits. Tents were constructed in RA stores in 1976 and 1977 in an attempt to control atmospheres and temperatures. This, unfortunately, was unsuccessful as there was no significant improvement in fruit quality.

In 1978, Elgin Fruit Packers Cooperative (ELFCO) sent D. H. Cunningham and C. Brislin to the USA to study CA storage in Washington State. On their return ELFCO built the first jacketed CA store for the 1979 season. In 1979 another study tour followed comprising two post-harvest technologists (L. Ginsburg and G. Eksteen), two consulting engineers (P. Worthington-Smith and P. Steynor), one operating engineer (P. van Bodegom) and two producers (S. Smith and J. Findlay). This group was later joined by D. Cunningham. This study tour took the group to England, USA, Belgium, Italy, and Israel and a large amount of information was brought back to South Africa. Growth in the CA storage industry commenced with 35 000 bins of CA storage coming into operation for the 1980 season.

During 1978, when the tents were being constructed in RA stores, a group of CA experts was formed with a view to exchanging information and expertise so as not to reinvent the wheel. During 1980, this became the CA Storage and Post-harvest Group which, in 1983, was taken under the wing of the South African Apple and Pear Producers' Association. Initially, four meetings a year were held to exchange information, both on failures and successes. This has subsequently been reduced to two meetings per year, one in May (after harvesting the crop) and the second in November, to discuss results. The group was known as the CA Storage and Operator's Group.

In 1983 the group persuaded the Deciduous Fruit Board to experiment with the export of fruit from CA storage during June, July and August, and 89 000 cartons of Granny Smith and 7 000 cartons of Top Red were then exported. The improvement in fruit quality during this period was significant. In the 1992 season 1 031 000 cartons of Golden Delicious, 330 000 cartons of Packman's Triumph, 350 000 cartons of late Top Red, 1 128 000 cartons of Granny Smith, 316 000 cartons of Starking and 138 000 cartons of Buerré Bosc were exported from CA storage making a total of 3 293 000 cartons.

The growth in CA storage capacity in South Africa is illustrated in the following table

TABLE 1: Growth in controlled atmosphere storage capacity in South Africa from 1978 to 2004

Year	**Number of 380-kg bins export**	**Capacity (tons)**	**Growth (%)**
1978	6 000	2 280	
1983	50 000	19 000	733.3
1984	118 000	44 840	136.0
1985	125 000	47 500	5.9
1986	150 000	57 000	20.0
1987	195 000	74 100	30.0
1988	240 000	91 200	23.1
1989	296 000	112 480	18.3
1990	350 124	133 047	23.5
1991	432 307	164 276	7.4
1992	464 147	176 376	9 6
1993	508 855	193 263	5.5
1994	520 759	203 903	2.4
1995	577 112	219 302	10.8
1996	591 612	224 812	2.5
1997	659 383	250 565	11.4
1998	683 383	259 685	3.6
1999	690 217	262 281	1.0
*2000	693 668	263 593	0.5
*2001	697 136	264 911	0.5
*2002	700 621	266 235	0.5
*2003	704 125	267 566	0.5
*2004			

* Estimates for capacity were used for year 2000 to 2004 since CA evaluations were only conducted on request by the ARC

CHAPTER 2

THE NEED FOR CA STORAGE

A. THE EFFECT OF CA STORAGE ON THE POST-HARVEST BIOLOGY OF POME FRUIT

J. C. Combrink & A. B. Truter

From the moment an apple blossom unfolds its petals, the tree has only one objective, and that is to perpetuate the species. It therefore strives to develop, mature and ripen its seeds as rapidly as possible. The fruit tissue must become senescent and die to achieve this. This is in conflict with man's need, which is to preserve the fruit tissue in a wholesome state for as long as possible. In lighter vein, quality maintenance can therefore also be defined as an endless, and often fruitless, struggle between man and fruit. Anyone involved in the maintenance of fruit should have a basic knowledge of the biochemical processes occurring in a fruit. With this knowledge at hand, its post-harvest behaviour can be predicted to a certain extent. It will take some of the guesswork out of many daily decisions that have to be made by cold store operators.

Post-harvest biology, as the name implies, deals with the events occurring after the fruit has been removed from the tree. However, events occurring while a fruit is still attached to the tree may influence its post-harvest behaviour, and no review will be complete without a brief reference to what happens in the orchard. Many factors, such as weather conditions, can affect cold storage potential and the reaction of fruit to post-harvest conditions, but these will not be discussed here. The development of a fruit on the tree will be discussed only in relation to its post-harvest biology.

Several excellent reviews on post-harvest biology have been written and the serious reader is referred to them for a comprehensive study (3, 21, 22, 24, 25, 53, and 63). This review of post-harvest biology and the effect which CA storage has on the physiology of fruit, will be limited to pertinent information that will hopefully give the reader an insight into the complex biochemical nature of fruit development. It will help him understand and appreciate recommendations made by scientists and managers and will suitably equip him for the long struggle against the fruit.

FRUIT DEVELOPMENT

TERMINOLOGY

Terms describing the different stages of development are often ambiguous or confusing. Green fruit refers either to fruit with a green skin colour or unripe fruit. The different stages of development are not discreet and many overlap. Gortner, Dull & Krauss (19) developed terminology applicable to fruit development based on biochemical processes. They consider the period of development as being complete when the fruit ripens, and define the different stages in the growth of a fruit as follows:

Development:
The entire period during which new tissue is formed and brought to morphological completion, and perfective chemical changes take place. The period of fruit development covers the stages of pre-maturation and maturation, the latter of which includes ripening.

Pre-maturation:
The developmental period to the onset of the maturation processes, and generally including at least half the interval between blossoming and harvest. This stage is characterized by extensive cell enlargement.

Maturation:
The stage of fruit development during which the fruit emerges from the incomplete stage to attain a fullness of growth (physiological maturity) i.e. the fruit will ripen to good edible quality after storage. Most of the maturation processes must take place while the fruit is still attached to the tree.

Ripening:

The terminal period of maturation during which the fruit attains its full development and its maximum aesthetic and edible quality. Changes taking place during this period are structural, biochemical and visual. For some fruits, ripening may occur either before or after harvest; for others the fruit must be detached for ripening to proceed.

Senescence:

The period following fruit development during which growth has ceased and the biochemical process of ageing replaces the perfective changes of ripening. Senescence may occur either before or after fruit harvest. Watada et al. (67) consider senescence as part of development since, in some plants, developmental processes continue until the death of the plant. They give general definitions that are not only applicable to the developmental stages of fruit, but also to other horticultural crops such as non-fruit vegetables and floral and nursery crops (Fig. 1). They have derived the following definitions to fulfil these needs:

Development:

The series of processes from the initiation of growth to death of a plant or plant part.

Growth:

The irreversible increase in physical attributes (characteristics) of a developing plant or plant part.

Maturation:

The stage of development leading to the attainment of physiological or horticultural maturity.

Physiological maturity:

The stage of development when a plant or plant part will continue developing if detached.

Horticultural maturity:

The stage of development when a plant, or plant part, possesses the prerequisites for utilization by consumers for a particular purpose.

Ripening:

The composite of processes that occur from the latter stages of growth and development through the early stages of senescence and that results in characteristic aesthetic and/or food quality, as evidenced by changes in composition, colour, texture or other sensory attributes.

Climacteric period:

The period in the development of some plant parts that involves a series of biochemical changes associated with the natural respiratory rise and auto catalytic production of ethylene. The climacteric period consists of the pre-climacteric, pre-climacteric minimum, climacteric rise, climacteric peak and post-climacteric phases.

Ageing:

Any increment of time which may (or may not) be accompanied by physiological change.

Senescence:

Those processes that follow physiological maturity or horticultural maturity and lead to death of tissue.

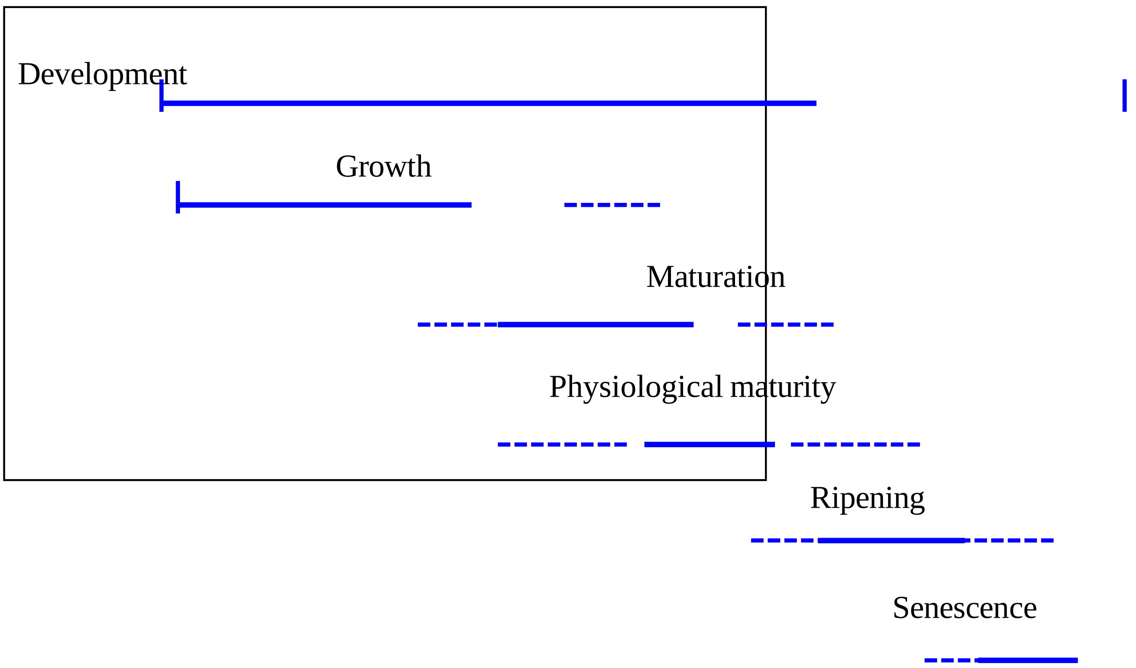

Fig. 1: Stages of plant development based on physiological processes (67)

Recognizing and interpreting these stages of development are very important. Quality maintenance is based on the correct determination of the developmental stage of a fruit at any given time. A fruit not harvested at the correct stage of maturity will have an inferior post-harvest quality. A fruit stored for too long will also have an inferior quality when it is eventually removed from the cold store. Using clearly-defined criteria, the producer or cold store manager should be able to identify this stage of development and treat the fruit according to its stage of development. This will ensure that only high quality fruit with good storage potential is selected for CA storage. Furthermore, it will ensure that the maximum storage life of the fruit is not exceeded.

FRUIT DEVELOPMENT ON THE TREE

Cell division, cell multiplication and differentiation of tissue occur during the first few weeks after fertilization (16). This is followed by cell enlargement and maturation. Both reducing sugars and sucrose increase throughout the period of growth and starch increases to reach a peak more or less a month before harvest (26). It then decreases, but considerable amounts of starch are still present at harvest. Malate accumulates in the fruit during the early stages of growth and then slowly decreases. The rate of respiration is high during and immediately after the cell division phase of growth. As maturity approaches, it decreases and remains relatively stable until the respiratory climacteric (Fig. 2) (16). The fruit phenolic content is high during the early stages, then decreases and remains constant until harvest (26).

Many factors such as fertiliser, irrigation and climate affect the growth and development of fruit. These all have an effect on the ultimate storage behaviour of the fruit (26, 55). The effect of climate and weather on keeping quality is discussed by De Villiers et al. (9).

MATURATION AND RIPENING

In the weeks preceding harvest, during maturation phase, numerous changes take place in the developing fruit (3, 26, 53, and 54). Most of the changes have to take place while the fruit is still on the tree. The total soluble solids content increases and starch decreases, there is a decrease in acid content, and there are changes in the pectic compounds that result in softening of fruit. Volatiles which determine the flavour or aroma are formed, pigments are formed in the skin or green pigments are converted to yellow pigments. Wax develops on the skin of fruit. The rate of respiration decreases and remains steady at a relevant low rate. The fruit attains its full size and reaches physiological maturity before ripening. Many of the changes are consistent and predictable and can be used as indexes for harvesting maturity (71).

The Climate

Respiration:
One index of metabolic activity is respiration, which can be expressed in terms of the release of CO_2 or the uptake of O_2 (16). Respiration is a degradable process occurring in living plant tissue. Stored organic materials (carbohydrates, proteins, fat) are metabolised to simple end products with a release of energy (heat of respiration). Oxygen is taken up in the process and CO_2 is produced (3). In simple terms, the chemical reaction can be expressed as follows (23):

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{kcal (heat)}$$

When apples are removed from the tree, a characteristic rise in the rate of respiration can be observed. This rise continues to a maximum and the decreases (Fig. 2). Kidd & West (16) called this phenomenon the *climacteric.* It has since become the most common phenomenon used to describe the physiological status of fruit. Many factors are involved and a clear understanding of the climacteric is essential in order to understand the changes occurring during fruit storage as well as the effect of the environment on the behaviour of the fruit. Prior to harvest, the rate of respiration decreases to a minimum, called the pre-climacteric minimum. The optimum stage of harvest maturity is just before this stage is reached. If fruit is harvested at or shortly before pre-climacteric minimum, low temperature (26) and CA storage (16) can maintain the low rate of respiration.

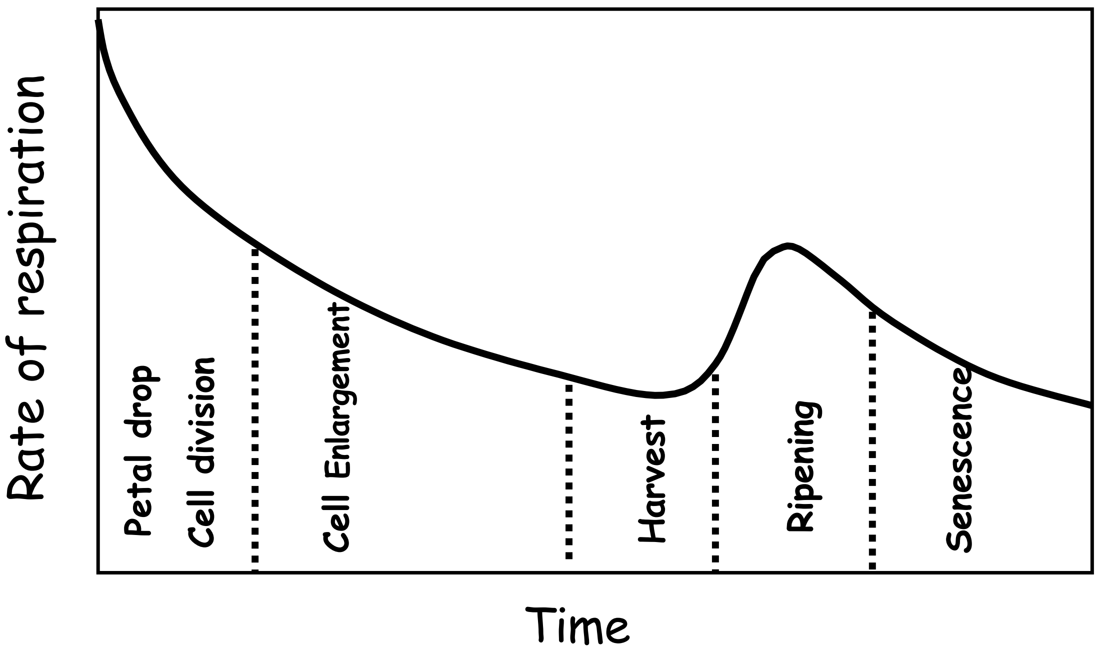

Fig. 2: Changes in the respiration rate of apples during the pre-climacteric and climacteric phases of development (16).

Changes occurring after this minimum are irreversible and low temperature cannot inhibit respiration. The rate of respiration increases sharply to a maximum after the pre-climacteric minimum. The rate at which this increase in respiration occurs is dependent on temperature (26) and the amount of 0_2 present in the atmosphere (16). This stage is called the climacterium. The fruit is now at an eating ripe stage and, if harvested, will be of good texture, sweet with a characteristic flavour, and acceptable eating quality. The rate of respiration decreases after the climacterium as senescence sets in. This stage is characterised by over-ripeness, mealiness and decay. It signifies the end of the life of the fruit.

Not all types of fruit have this respiration pattern. In some, the characteristic rise in the rate of respiration is absent. Based on the type of respiration pattern, fruit is classified as climacteric and non-climacteric fruit. All deciduous fruit except grapes belong to the climacteric group.

During respiration sugars are converted into CO_2 and water and energy in the form of heat. This heat of respiration, or vital heat, is always part of the refrigeration load that must be considered during handling of fruit (23). Heat evolution is expressed in terms of Joules and can be calculated from the respiration rate (Table 2). For each milligram of CO_2, produced by respiration, 2,55 calories of heat are generated. One calorie equals 4,187 Joules. Heat evolution is computed by multiplying each milligram of CO_2 by 10,676 (2,55 cal/mg x 4,187 J/cal.).

The rate of respiration is dependent on temperature. Van't Hoff, a Dutch chemist, found that the rate approximately doubles for each 10°C rise in temperature (54). He used the term Q_{10} = R2/R1 or a constant of about 2 to describe this relationship where Q = quotient, 10 = °C and R = rates of reaction at temperature 1 and 2. The Q_{10} may not be the same over a large temperature range.

However, as a general rule it can be said that an apple or pear will ripen as much in 1 day at 21°C as it will in a week at 0°C.

Table 2: Respiration rates of some deciduous fruit at different temperatures (23)

Commodity	**Respiration rate (mg CO_2/kg/h) at:**			
	0°C	**10°C**	**15°C**	**20°C**
Apples (early)	3-6	14-20	18-31	20-41
Apples (late)	2-4	7-10	9-20	15-25
Apricots	5-6	11-19	21-34	29-52
Peaches	4-6	16	33-42	59-102
Pears (Bartlett)	3-7	8-21	15-60	30-70
Plums (Wickson)	2-3	7-11	12	18-26

Production of ethylene

Ethylene is a simple organic compound which can cause physiological responses in plant tissues even when present in trace amounts (3, 4, 47, 53, and 70). It stimulates fruit to ripen and an increase in ethylene production is usually associated with an increase in the rate of respiration. Some fruit will produce ethylene and ripen when it reaches a certain stage of maturity.

However, some need an exogenous application of ethylene immediately after harvest to stimulate ripening. To ensure even ripening of such fruit, ethylene must be applied. Ethylene production is stimulated by storage at a low temperature for 10 to 14 days. Pears stored for 14 days or longer at -0,5°C will ripen normally and evenly (66).

Ethylene is generally considered to be a ripening hormone (5, 53). However, production of ethylene is not always associated with a climacteric. Ethylene is produced during low temperature storage without a concomitant increase in the rate of respiration.

Fidler & North (14) and Truter & Combrink (61) found high concentrations of ethylene in apple and pear cold stores. However, no effect on fruit quality was observed.

EFFECT OF CA STORAGE ON POST-HARVEST BIOLOGY

Much research has been directed toward determination of optimum storage conditions and the operation of CA facilities. Only a small percentage of the reports on CA storage dealt with the mode of action of reduced O_2 and elevated CO_2 concentrations (31). The nature of the respiration reaction and the respiration quotient (Q_{10}) indicates that O_2, CO_2 and temperature are the most important factors influencing the metabolism of fruit. Decreasing the O_2 concentration or temperature, or increasing the CO_2 concentration, has major effects on all metabolic processes occurring in fruit during storage (72)

Kadler (31) gave a review of the biochemical and physiological basis for effects of controlled and modified atmospheres on fruit and vegetables. He concluded that there is a need for more knowledge on the effect of CA on metabolic changes. Since his review, much research in mechanisms involved in CA storage has been done, but a lot more remains to be done. Cultivation practices, storage and cultivars vary from country to country and these all have an effect on the behaviour of a fruit during storage. Results from one area cannot be directly applied to another area. As more knowledge on the effect of CA storage on post-harvest biology is gained, storage conditions may also have to be adapted to strike a balance between beneficial and detrimental effects of CA storage.

Effect on uptake of O_2 and production of CO_2

An increase in the CO_2 concentration suppresses the rate of respiration (12). At temperatures above 1,7°C the rate of respiration is controlled by the O_2 concentration, but below this temperature, O_2 limits the process from between 2% and 10% only. It is therefore essential that the O_2 concentration is decreased to below 10% as soon as possible after harvest. The respiration rate decreases with decreasing O_2 concentration in the presence and absence of CO_2 (Table 3). The effects of O_2 and CO_2 are therefore additive. Although the effects are additive, there is evidence that O_2 has a more pronounced effect than CO_2 on the respiration of Bartlett pears (32).

Table 3: Rates of respiration at 3,3°C relative to rate in air = 100(12)

Gas	**Rates, relative to air = 100**	
CO_2:O_2	**$C0_2$**	**0_2**
Air	100	100
0:10	84	80
0:5	70	63
0:2	63	52
0:1,5	39	-

Respiration patterns at low O_2 and elevated CO_2 concentrations have different phases (12). Firstly, there is an adjustment to temperature followed by a relatively steady phase during storage. An increase in respiration may occur towards the end of the storage period if physiological injury occurs or decay sets in. At 3°C the production of CO_2 is halved when the O_2 concentration is decreased to between 2% and 3% (12). If no physiological injury occurs, the respiratory activity in controlled atmosphere is more or less the same for all cultivars (11, 12). When pears are transferred from a low O_2 controlled atmosphere to air, the rate of respiration remains low for a few days after transfer, indicating that the low O_2 concentration has some residual effect on respiration (33).

The effect of CA on respiration cannot easily be quantified in terms of the amounts of CO_2 produced. Many factors, such as cultivar, gas composition used, maturity at harvest, rate of atmosphere modification, temperature, fruit size and skin porosity, may affect respiration. Solomos (58) applied Fick's first and second laws of gas diffusion to describe the effects of low

O_2 concentration on respiration and gas exchange in bulky tissues (5). Blanpied (2) also used Fick's law to estimate the amount of N_2 to scrub ethylene from the cold storage atmosphere.

A minimum of 1% to 3% O_2 around fresh fruit is required to avoid a shift from aerobic to anaerobic respiration (31). During anaerobic respiration the metabolism of the fruit is altered in such a way that acetaldehyde and ethanol are formed. Off-flavours develop and the fruit becomes inedible. Golden Delicious apples stored at 0% O_2 for 14 weeks, had a lower total soluble solids content but were firmer than comparable fruit stored in 0,5% to 1,5% O_2 (48). In 0% O_2 within a given CO_2 concentration, ethanol accumulation is linearly related to the duration of the exposure (51). At ambient temperature in air the fruit loses about 50% of the ethanol within 1 week (48). Considerable deviations from the target atmospheres other than total anoxia can be tolerated, as no internal or external ethanol injury symptoms were observed after 14 weeks of complete anoxia (51). However, not all ethanol is lost when a fruit is transferred to air (15). The incidence of decay, internal breakdown and core flush may increase. It is therefore advisable to avoid extended periods of total anoxia.

Effect on production of ethylene

The rate of ethylene production is a function of temperature. The lower the temperature, the lower the rate of ethylene production (14). O_2 is required for the conversion of 1-aminocyclopropane-1-carboxylic acid (ACC) to ethylene (52) and high CO_2 concentrations inhibit the process (6). CA storage therefore has a significant effect on ethylene production. It retards ripening caused by auto catalytic production of ethylene (27). In RA at 3,5°C, Golden Delicious apples produced ethylene after 8 days, in 5% CO_2 /3% O_2, after 44 days and in 2% O_2 alone after 35 days (34). Ethylene inhibition is therefore due to the combined effects of CO_2 and O_2 (4) but the effect of O_2 is apparently larger than that of CO_2 (52). The extent to which the O_2 concentration is decreased affects the level of ethylene inhibition.

Several researchers (1, 2, and 10) recommend the removal of ethylene from cold stores to prevent detrimental effects on quality. However, ethylene effects occurring at 2% to 3% O_2 are significant in 1,5% and 1,0% O_2 (2). Removal of ethylene from storage atmospheres is therefore not necessary (2, 38, 39, and 61). The production of ethylene is inhibited at low temperatures and modified atmospheres, and even if some ethylene is produced, it appears to have no harmful effect on fruit quality. The effect of atmosphere modification is apparently relieved when fruit is transferred to air (34). In Bartlett pears transferred from a low O_2 atmosphere to air, the production of ethylene was lower, the lower the CO_2 concentration (33).

Effect on aromatic volatiles

The volatile flavour compounds of apples have been studied extensively and over 250 volatiles identified (69). The most important are esters, alcohols and aldehydes (20, 69). Some esters are produced in low amounts but they may make a contribution to aroma which is disproportionate to their concentration (50). Aromatic compounds complement each other to produce a characteristic flavour and it may be misleading to express aroma in terms of the concentration of a specific substance alone.

Decreasing the O_2 and increasing the CO_2 concentration affects aroma production in apples and pears. Reducing the O_2 concentration inhibits the production of aromatic volatiles of apples (50, 60, and 69) and pears (13). This effect becomes more marked with an increase in the length of the storage period (42, 60). O_2 has a more pronounced effect than CO_2 (60). There is also a considerable difference between the effects of 3% O_2 and 1% O_2. Sensory panels rated McIntosh apples stored in 1% O_2 higher than those stored in 3% O_2 on juiciness and overall acceptability, but these apples lacked an intense flavour (41, 43).

Removal from CA storage does not always result in an increased production of aromatic volatiles. The extent of recovery decreases as the length of the storage period increases, and the fruit retains a residual CA effect which prevents it from producing volatiles (50, 60). The inhibiting effect can be decreased by increasing the O_2 concentration (57). Raising the O_2 concentration from 1,25% to 2% improved aroma production of Cox's Orange Pippin apples without decreasing the firmness of the fruit. Differences in fruit firmness could be detected when a penetrometer was used to measure firmness, but a sensory panel could not detect any differences. The inhibitory effect of low O_2 is probably due to the fact that the availability of alcohol, from which the aromatic esters are derived, is limited (35).

The effect of the length of the storage period on the production of aromatic volatiles is significant. The beneficial effect of retaining flesh firmness and colour must be weighed against the loss of aroma production. A consumer survey carried out in the United Kingdom showed that overall acceptability of fruit was principally related to texture (57). Loss of the ability to produce volatiles after storage need not therefore be a factor which limits the length of the storage period. However, the extent of volatile production is also affected by the harvesting maturity (8, 50). If fruit of an inferior quality is stored, the decreased ability to produce volatiles after storage will be more pronounced than that of high quality fruit. To maintain quality and ensure that even prolonged storage does not affect these quality attributes significantly, careful selection at harvest of fruit for long term storage is extremely important. If there is any doubt about the storage potential of fruit, the quality of the fruit should be monitored closely and the cold storage period limited. There seems to be some merit in increasing the O_2 concentration shortly before opening a cold store to regenerate volatile production.

BENEFICIAL EFFECTS OF CA STORAGE

The major benefit of CA storage is the prevention of ripening by retardation of the process regulating ripening and senescence (29). Most of the enzymatic processes occurring in fruit after harvest are O_2 dependent and lowering the O_2 content around the fruit reduces the activity of the enzymes (68). Ethylene plays an important role in ripening (5) and CA storage prevents the auto catalytic production of ethylene (45). By delaying ripening, the onset of the climacteric is delayed and the storage life of the fruit is extended. Longer storage life for fruit allows regulated marketing over a long period. Under CA storage, apples and pears of a high quality are available for longer periods than in the past and the quality is much better than after RA storage for shorter periods. This is of benefit both to producers and consumers.

High gas concentrations (3% O_2/15% CO_2) were used initially, and even these prevented loss of quality (17). Lower gas concentrations (1,0% O_2/1,5% CO_2) further reduced quality losses such as loss of acid and firmness (44). Good results were also obtained at 0°C with low gas concentrations for 3 months followed by storage at 2,5% 0_2/3,0% CO_2. The more rapidly the 0_2 concentration in the store is decreased, the better the retention of firmness and texture (37, 40). However, the rate of CA establishment becomes less critical if the fruit is cooled rapidly (64, 65). The reduction in the rate of softening is probably due to the accumulation of polyamines which inhibit the activity of polygalacturonase, the enzyme which degrades the cell wall (36).

The advantage of ultra-low O_2 storage is that the incidence of flesh disorders, such as bitter pit and superficial scald is reduced (28, 46, and 62). Initial O_2 stress induced by keeping fruit at

0,5% O_2 for 10 days prior to conventional CA storage also reduces the development of superficial scald (46, 73, 74).

CA storage reduces changes in colour by reducing the rate at which chlorophyll is metabolised (17, 68). Low O_2 levels slow down the decomposition of carbohydrates. Losses in total sugars are smaller, the lower the O_2 concentration in the storage atmosphere (68). Increasing the CO_2 content of the storage atmosphere slows the process down even further. Some apple cultivars are sensitive to low temperatures. The storage life of these fruit can be extended by CA storage at temperatures which can be tolerated by the fruit.

HAZARDS OF CA STORAGE

CA storage is not the answer to all quality maintenance problems. It can sometimes be responsible for considerable losses. The hazards of CA storage become apparent when recommendations based on research are not implemented correctly.

Maintenance of the correct O_2 concentration is important. Low O_2 injury occurs when the O_2 level is below a certain threshold. Aerobic respiration is replaced by anaerobic respiration, and alcohol and acetaldehyde are produced. These lead to off-flavours which render the fruit useless. In some cases, the alcohol will disappear during aeration of the fruit (48).

Granny Smith apples are highly susceptible to core flush. CA storage is one of the factors that may aggravate this disorder (49). Its incidence can be decreased by increasing the storage temperature (7) and keeping the CO_2 concentration low, especially at low temperatures (18).

Low O_2 concentrations have an effect on the ability of fruit to produce aromatic volatiles which are responsible for the characteristic flavour (42, 60). Transferring the fruit to air may regenerate volatile production, but not completely.

Quality maintenance by means of CA storage requires knowledge of the basic principles involved in post-harvest biology. The variation between fruit makes it impossible to predict with certainty what the effect on fruit quality of a specific storage environment will be. However, general guidelines can be formulated. In some cases, deviations from these guidelines are not detrimental, but without some understanding of the respiration and other processes occurring in the fruit, it is impossible to determine how far one can deviate from the recommended conditions. In this section, it is explained that the quality maintenance is dependent on delaying senescence; the more efficiently senescence is delayed, the better the quality maintenance. To be successful, the rate at which some processes take place must be slowed down. This explains the need for rapid cooling and atmosphere modification. More research under local conditions is required to determine, for example, at what rate O_2 is consumed and CO_2 produced, and at what rate ethanol accumulates under different conditions.

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CHAPTER 3

CONSTRUCTION OF CA BUILDINGS

P. C. van Bodegom, J. S. Findlay and L Robinson

The sizes of CA stores in different countries is a matter of marketing policies, but as a rule of thumb, it can be said that everyone agrees that a store should have such a capacity that the fruit in the store can be packed and marketed within 2 weeks after breaking the gas seal, to keep optimum quality.

In larger stores, it is possible to break the seal, open the door, take out as much fruit as is needed, close and seal the door again and with the aid of generators and/or nitrogen flushing re-establish the CA conditions as soon as possible. It is not recommended to do this more than once.

The number of CA units and the maximum RA storage period after which CA storage is undertaken is more a policy of quality that is laid down by individual organisations.

The most economical size of CA stores, both from a marketing and quality point of view, varies as follows:

Storage capacity up to 50 000 bins: 500 – 1 000 bin stores

Storage capacity over 50 000 bins: 600 – 1 600 bin stores

The first stores to be built in South Africa were the jacketed type of CA store within an existing RA room built of marine-ply and sealed with polaroof paint. All CA stores in South Africa are now built with polystyrene sandwich panels, gas-sealed with polaroof or equal approved, with bandages on all joints and corners.

In South Africa, all stores are pressure-tested annually prior to use, using an ordinary vacuum cleaner either with positive or negative pressure of 26 mm of water gauge. This should not drop more than 5 mm over 30 minutes for a good gas-tight room. Rooms are normally tested under positive pressure but if problems are found with the gas sealing, it is easier to find the gas leaks with a negative pressure with the assistance of someone inside the room. Never allow the pressure to rise above 30 mm of water gauge as this can cause enormous stress on the buildings. Walls have been known to collapse under too high a pressure.

Construction

There is a variety of different types of structures throughout the world. In most cases the cost of different suitable types of building material in different parts of the world is a consideration. In others, it is in accordance with insurance regulations. Only one aspect in the consideration of construction applies everywhere the labour force erecting, converting or building such a structure must be qualified and skilled in order to achieve a perfect gas-tight structure.

The following is a summary of details from a CA investigation tour during 1979.

United Kingdom:
The size of stores varies from a normal store with a capacity of 150 tons of fruit to stores with a maximum capacity of 300 tons. One bin of apples = 0,38 tons and one bin or pears = 0,44 tons). Fruit should be packed and marketed within 5 days of breaking the gas seal.

New stores are erected from complete panels made in the factory and or on site. This is also a sandwich type of panel with tongue and grooved joint, made by Betalock. The steel used is Stelvitit-G and is made by British Steel with a thickness of 0,6 mm.

In conversions of stores, metal sheeting is fitted on the inside of the store over insulation and attached to the timber framework; joints are sealed with fibre-glass and painted over with a gas-tight type of paint, such as Steridex. In the older stores the inside is sometimes completely covered with Otina-A grease for joints and a heavier type Otina-C grease for doors and inspection hatches. Door openings are made gastight installing a sophisticated gas-tight door, sometimes still taped around the outside, or a construction of gas-tight panels on the inside of the door, fitted separately in the door frame and sealed with grease. Floors of existing stores are sealed with a bituminous type of mastic, available from Shell Chemicals that is mixed with 6mm stone chips, sand and cement and applied as an extra floor layer of 10 - 12 mm thickness. A polyurethane type varnish (Oxanol) is also sometimes used to seal existing floors, this product being originally a dust sealer. At the joint from the wall to the floor, a softer type of mastic or bituminous compound is used.

United States of America:

Conversions are not very successful due to gas leaks developing as a result of expansion and contraction of the buildings. If a conversion must be made, the only successful types are the jacketed types with a plywood box-type construction inside an existing cold store. This structure is made gas-tight by spraying polyurethane on the inside. The tilt-up system is widely used for the construction of new buildings. This system consists of concrete panels cast on site, up to 20 feet wide (6,1 m) and 32 feet (9,76 m) high, tilted up by a crane and bolted together with a roof construction of laminated timber beams or lattice trusses decked with plywood and waterproofed externally with a bituminous type of material.

According to Ron Cameron, the main reason for changing from metal to concrete building in the USA, was the raising of insurance rates for these specific type of buildings. Also the protective layer that is placed over the layers of urethane is in accordance with regulation by the fire departments. This layer is a mixture of plaster and a certain chemical and is obtainable as a pre-mix.

Wood is a major building material as it is reasonably inexpensive in Washington State.

Doors are in many cases made out of one panel which is placed in front of the door opening and clamped down onto the door frame so that it is gas-tight.

Floors are normally sealed on top with a sealant sprayed on afterwards and joints are sealed with a rubber type of compound. Internal walls can be made out of plywood (± 10mm thick) on timber frames and the joints sealed with fibre-glass tape and painted with Gacoflex.

In the USA, a good CA room costs 25 - 30% more to build than a RA room. In Washington State, conversion has been abandoned as experience in the last 15 years has proved that it is too costly.

Capacities of CA stores in the USA vary considerably between 1000 - 2 500 bulk bins depending on sizes and marketing policies of different companies.

Holland:

CA storage was started here in 1953 with the jacketed principle type of store consisting of welded metal boxes inside existing stores.

For the same reasons as in the USA, conversion of stores was abandoned and at present the new stores consist of sandwich type panels, which are erected inside a steel framed or masonry type of building and joints are sealed with a tape that is used in the aviation industry and covered with a gas-tight type of paint. Sizes of stores vary between 50 and 200 ton capacity.

Italy:
Most stores are made out of sandwich type panels supplied by Isolcell. The OBSI Fruit Handling Cooperative has 23 rooms of CA storage space for 7 000 tons of fruit, with capacities of 220-700 tons per room. OBSI handles a total of 10 000 tons of fruit from 78 members.

A special Italian-made gas-tight door is also used. The principle being that by closing the door, the door is lowered onto a V-notch that pulls itself tight against the doorframe due to its own weight.

Israel:
Here again the newer stores are of polyurethane sandwich type panels using galvanised steel. Joints are sealed with metal strips and mastic underneath to give the gas-tight seal. Another type used is a completely welded construction on the outside to give the gas and vapour seal.

A special pre-cooling store in Ashdod is loaded from the top by three cranes of 16 tons capacity each, with container loads of citrus on special frames. Air movement is vertical from the top. Pre-cooling capacity is 500 000 cartons/week on day and night shifts with a total turnover of 4 - 5 million cartons/year. Sizes of complexes vary, like the one at Kiryat Shemona with 30 000 ton capacity of which 23 000 tons are CA, which is one of the biggest. There are 113 rooms in total.

Burp tubes or pressure relief systems

The most important factor of pressure relief valves or burp tubes (Fig. 4) is that the water covering the knife-edge should never be deeper than 10 - 12 mm, otherwise considerable pressure can build up inside the store. It is not really the surface area but the depth of water that is the critical factor. As frost is inclined to accumulate, the use of glycol in the burp tube or a saline solution that does not freeze is suggested. Glycol is preferred. Burp tubes are 600 mm long with a tray of water/glycol on either side of the insulation with the depth of water 100 mm under the knife-edge but only covering the knife-edge by 10 - 12 mm (Fig. 4).

As there is always water condensing on the knife-edge plate due to cold on the one side and heat on the other side, these trays of water will always remain full. It will get too full unless a 6-12 mm hole is drilled in the external tray 10-12 mm above the bottom of the knife-edge to let out the excess water.

To cope with over- and under pressure inside the CA room, a pressure relief system is always used. In England, a spring-loaded valve by the name of Beta Safe is widely used. This relief valve handles over- and under pressures and is mostly set between 1/2" - ¾”" (12,5 - 19 mm) of water gauge. In Italy, a PVC type of T-connection is used as a pressure relief valve. The pressure is set with an increase or decrease of the weight of the valve plate.

Pressure testing

All CA stores must be pressure tested annually before operation. Generally the stores are pumped with a positive air pressure inside of 25 mm of water gauge, whereafter a certain time is allowed for a drop in pressure.

a) In England, this pressure is allowed to drop to 3/4" and when dropping further from 3/4" to 1/2” it must take a minimum of 7,5 minutes for a store with a capacity of 150 tons.

b) In Holland, the pressure is kept at 10 mm of water gauge. Positive air is pumped in to keep the pressure at 10 mm of water gauge. By measuring the amount of air that is pumped in, a leakage factor is arrived at for a certain room. A diagram will then tell if it is within the limits.

c) The USA uses a positive pressure of 1" water gauge, that is allowed to fall to 0,2” - 0,3” of water gauge over 1 hour, with an absolute maximum fall of 0,2” of water gauge in 20 minutes.

Air bleed to increase 0_2 intake

This was done with all types of valves, such as PVC ball valves, PVC gate valves, etc. Galvanised reducing bushes are also used, the one screwed into the other reducing from 75 mm to 12 mm to finally close this bleed system completely with a plug. More modern methods are described elsewhere.

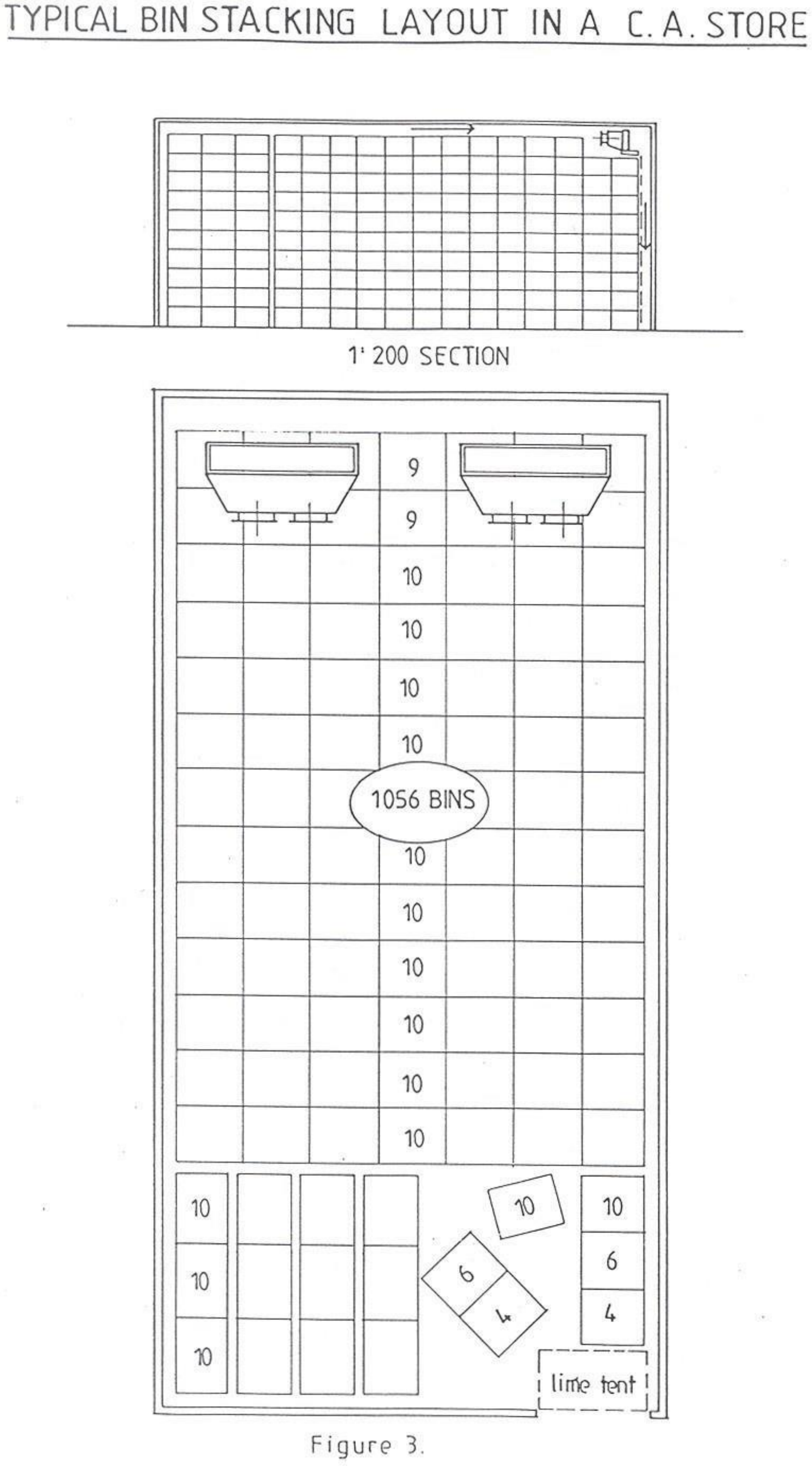

Figure 3. Typical bin stacking layout in a CA store

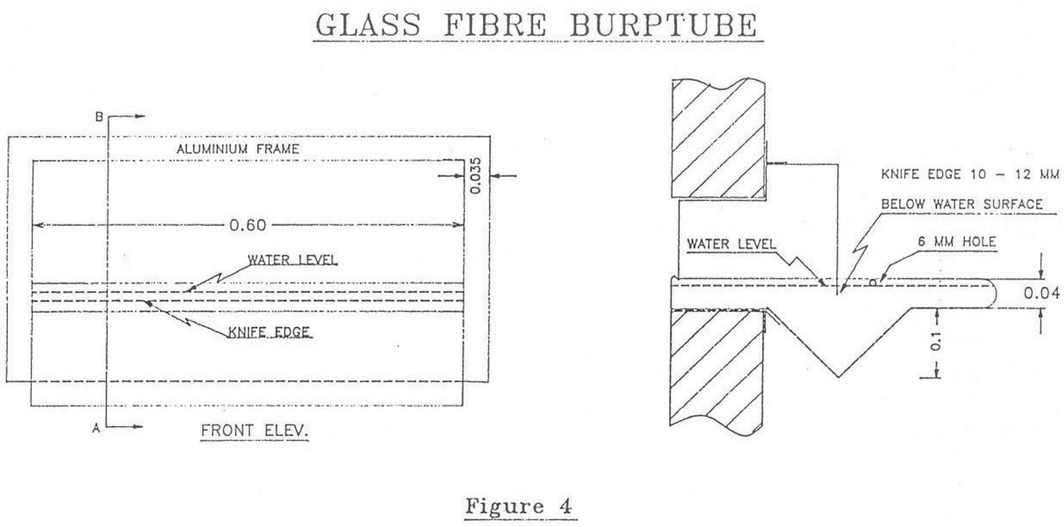

Figure 4. Glass fibre burp tube

CHAPTER 4

REFRIGERATION IN CA STORES

J S Findlay

Coil size and position in CA stores

Most CA stores in South Africa are built to a modular size of 1040 bins (Fig. 3). The coil size is designed with sufficient surface area to pull down 300 bins of fruit per day from 30°C to 0°C (i.e. in 24 hours) with a coolant temperature of -10°C and to be able to hold the store at -0,5°C with a coolant temperature of -2°C. The cooling coils should be placed at the far end of the room, opposite the door so that cooling can commence as soon as fruit is placed in the room.

Refrigeration control and safety features

There are normally four or five probes in each room measuring the temperature:

- air off the coils
- air return
- two or three probes in the fruit themselves, one in the coldest part of the room which is normally the bottom bin in the stack at the back of the room, and one in the hottest part of the room which is normally a bin which is fairly high up in the store at the far end of the room from the coils.

There is normally a temperature gradient across the room of 0,5°C. If one tried to eliminate this temperature gradient, the air quantity through the bin plenums would have to be too high and it could cause wilting of the fruit during the holding period.

A mercury or alcohol thermometer hung through a penetration into the room to check the air off the coil once per week, does assist in checking the calibration of the temperature instrumentation. A low temperature sensor on the back wall of the store to cut off the refrigerant, is essential to prevent freezing damage if the air temperature drops too low.

Defrosting

Defrosting can be done either by means of cold water from the mains or with hot gas from the high-pressure side of the machine room. With cold water, make sure that the drip tray and pipe sizes are large enough to carry away the run-off. With hot gas, heating elements must be placed in the drip trays and around the take-away pipes inside the store to prevent ice build-up and thus blockage. All take-away pipes must have a continuous fall so that defrost water can drain completely. With cold water, the pipes bringing the water to the sprinklers or headers above the coils must be able to drain completely, otherwise, if water remains in them, it freezes and blocks and no defrosting can take place. With pull down and a large temperature difference between coolant and air, the CA store will require defrosting once or twice per day, but once the store has reached holding temperature and there is a small temperature difference of 1°C to 2°C, it should be able to extend defrost periods to once per week. A pressure differential switch can be installed on either side of the coolers which will switch on a light in the control panel when there is ice build-up in the coils.

After defrosting has been completed, it is essential to ensure that there is a time delay for the cold refrigerant to pass through the coils so that they can come down to room temperature before the fans start up, otherwise a very large pressure change results inside the store which can empty all water/glycol out of the burp tubes and even cause gas leaks in the gas seal. Defrosting can be done automatically, but it is advisable to do it manually so that pressure changes in the store can be checked. A light over the coils with a window to enable viewing of the condition of the coils is useful.

Temperature recording and control

The normal recording points are: air off the coils, air return and two or three probes into the fruit to check the core temperature of the fruit. This is normally done in the coldest part of the room, i.e. the bottom bin at the back of the room, under the cooling coil, and in the warmest part of the room where the bin is fairly high up in the stack furthest away from the cooling coils.

Temperature control has been done from the set point on a Versapak or equal approved device to control the back pressure regulator, thereby controlling the boiling point of the refrigerant in the cooling coils. A safety thermostat is always installed fairly low down on the back wall of the room which will cut off the refrigerant to the room if the temperature drops too low and freezing damage could occur. It has always been a good idea to have a mercury or alcohol thermometer through a penetration into the room in the air off the coils so as to do a final weekly check on the electronic recording equipment.

Most temperature recording is now done through a data-logger in the smaller complexes whereas the larger complexes have total recording and control through their computer-controlled instrumentation system combined with gas analysis.

Basic refrigeration statistics

The metric refrigeration unit is the calorie. One calorie is the amount of heat required to raise one gram of water 1°C. The imperial unit is the British thermal unit (BTU). One BTU is the amount of heat required to raise 1 lb of water by 1°F. One BTU = 0,252 kilo calories.

The specific heat of apples and pears is 0,87 BTU per pound per °F in Imperial or kilo calories per kilogram per °C in metric units.

One bin of apples weighing 380 kg (837 lbs) requires 36 432 BTU (9 180 k cal) to bring the temperature down from 82°F (28°C) to 32°F (0°C) + 10% for the container, say, 40 000 BTU or 10 000 k cal.

One bin of pears weighing 440 kg (967 lbs) requires 42 184 BTU (10 630 k cal) to bring the temperature down from 82°F (28°C) to 32°F (0°C) + 10% for the container, say 46 400 BTU or 11700 k cal.

Heat of respiration

During respiration energy is released in the form of heat. The amount varies with the commodity and increases as the temperature increases up to 38°C to 40°C (100°F to 104°F). CO_2 is given off as the fruit respires and for each milligram of CO_2 produced by respiration, 2,55 cal of heat are generated. This also forms part of the heat load in calculating the cooling requirements.

Table 4: Respiration rate of apples as rates of CO_2 production in mg/kg/h at various temperatures:

Degrees C:	**0**	**5**	**10**	**15**	**20**
Apples-Summer	3-6	5-11	14-20	18-31	20-41
Apples-Winter	2-4	5-7	7-10	9-20	15-25

Table 5: Heat of respiration in k cal per ton of apples/24 h at various temperatures:

Degrees C:	**0**	**5**	**10**	**15**	**20**
Early cultivars	200-350	320-650	850-1260	1108-1900	1200-2500
Late cultivars	110-350	270-430	420-640	570-1200	900-1500

The rate of respiration as illustrated above, is 6-10 times faster at ambient than at 0. The closer to freezing, the slower the respiration rate.

Hydro-cooling of apples and other fruits

Hydro-cooling is without doubt the fastest way to cool fruit, except for possibly vacuum cooling of lettuces and such-like products.

The following figures give the time taken for fruit to reach certain temperatures in water containing crushed ice, with a water temperature of between 1°C to 2°C.

Fruit temperature O°C	**Time taken to reach temperature (minutes)**
20,5	0
14,5	6
10,0	12
4,5	23
1-2	45

It actually becomes impractical to try to bring the fruit down to 1-2°C in water as the time taken is too long for the heat exchange and thus 4,5°C is a more practical temperature, but still a long time to keep fruit in a hydro-cooling drench. Having brought it to 4,5°C, one still has to have the forced-air cooling infrastructure to take the fruit down to the optimum holding temperature of -0,5°C which water could never do.

Secondly, with hydro-cooling, the heat load is very high and requires a very high compressor capacity for short periods of time, whereas air cooling provides a constant heat load for a 24 hour operation. Recycled water becomes very dirty and either has to be filtered (expensive) or changed and chlorinated to prevent the spread of fungal spores. Experiments done by Schomer on the effects of hydro-cooling on apples in the USA, showed no significant difference in quality after 7 months storage when compared to apples cooled in good commercial storage down to -0,5°C in 48 hours. If the apples took longer than 7 days to come down to temperatures in air, then there was a benefit in hydro-cooling down to a core temperature of 4,5°C. Thus hydro-cooling is not used commercially in deciduous fruit storage in South Africa.

Evaporative cooling does have significant benefits and fruit washed with clean cold water (containing chlorine) on the way to the cold store, can achieve up to 10% saving in heat load.

REFERENCES:

HARDENBURG, R E., WATADA, A. E. & WANG, C. Y., 1986. The commercial storage of florist and nursery stock United States Department of Agriculture, Agricultural Handbook No. 66. Government Printing Office, Washington DC.

CHAPTER 5

AIR MANAGEMENT IN COLD STORES

J. S. Findlay

Air movement through the bins and the fruit itself is one of the most important means of cooling the fruit and holding the fruit at the correct temperature during its storage life. Too much air through the bin plenums will result in excessive wilting of the fruit in the store and too little air movement will result in too great a temperature gradient across the stack.

It is preferable to have the coolers at the far end of the room opposite the main door so that cooling can commence as soon as the first fruit is loaded. The optimum length of the stack has been found to be 13 bins. With longer stacks, the air quantity has to be increased considerably to avoid a temperature gradient. An acceptable temperature gradient down the length of a CA store is 0,5°C.

Curtains must be installed to direct the air flow and prevent it from going down the gap between the bins and the side walls. Bins are normally stacked nine-high under the coolers. The curtain is normally hung across the top five bins as well leaving the plenums of the four bins on the bottom open. This prevents air from short-circuiting back to the coolers (Fig.3).

In South Africa's standard 1040-bin cold stores the air has been very successfully distributed by four axial flow aerofoil bladed fans, two fans per cooler block supplying 15 000 m^3/h of air at a static pressure of 10 mm of water gauge, each fan motor absorbing 1 kW.

The fan motor should be protected to IP55 standard suitable for operation in saturated atmospheres. This quantity of air gives forty air changes per hour in the empty room and an air speed of 300 m/min through the 28 open-bin plenums.

The need for rapid air circulation is greatest during removal of field heat. Sometimes this heat is best removed in separate pre-cooling rooms that have more refrigerating and air moving capacity than the regular CA storage rooms. One must remember that for pears it is more beneficial to reach the desired holding temperature quickly whereas for apples, the required gas concentration is more beneficial, using some of the field heat in the apples to obtain rapid CA conditions.

After field heat has been removed, a high air velocity is unnecessary and usually undesirable. Only enough air movement should be provided to remove respiratory heat and heat leakage from external sources. The air must be directed in such a way that it flows uniformly to all parts of the room and the product. In the USA they recommend air movement during the holding period of 15-25 m/min uniformly through all the stacks. They design their apple and pear storage air circulation systems to provide 28 m^3 of air/minute/short ton of refrigeration capacity.

In filling the last 4,5 m of the CA store, when the bins have to be turned through 90°C to allow for forklift access, it is essential to have the necessary gaps of 150 mm to 200 mm between stacks to allow for adequate air flow (Fig.3).

REFERENCES

1. *HARDENBURG, RE. WATADA, A.E. & WANG, CY, 1986. The commercial storage of florist and nursery stock United States Department of Agriculture, Agricultural Handbook No 66. Government Printing Office, Washington DC.*

2 *WORTHINGTON-SMITH & BROUWER & Personal Communication.*

Chapter 6

Recommended temperature and gas regimes for cold storage of South African commercial apple and pear cultivars

Compiled by ARC Infruitec-Nietvoorbij in co-operation with SA Apple & Pear Producer's Association

Revised and updated annually by Anél Botes; ARC Infruitec-Nietvoorbij; JA van der Merwe (Consultant HGS), January 2023

IDEAL STORAGE CONDITIONS	PRIMARY PRINCIPLE	ADDITIONAL INFORMATION
Temperature	**RA-storage**: core temperature must be -0,5 °C within 48 hours of harvest	Hold temperature at -0,5°C for duration of storage
	CA-storage: core temperature must be -0,5°C within 96 hours (4 days) from harvest.	Rapid removal of field heat to a core temperature of -0,5°C is more beneficial than rapid attainment of the required gas regime.
Relative humidity (RH)	Must be between 90% and 95%.	Applicable to both RA and CA-storage. It is difficult to measure relative humidity accurately, but most cold stores are designed to maintain a high relative humidity.
Gas Regime (see Appendix 1)	**Nitrogen flushing**: must reach 3% O_2 + 1,5% CO_2 (0% CO_2 for Bon Chretien and Forelle) within 4 days of sealing the room.	The optimum gas regime for the specific cultivars must be reached as quickly as possible thereafter, but within 7 days of sealing.
	Nitrogen generator: must reach 3% O_2 + 3% CO_2 (0% CO_2 for Bon Chretien and Forelle) within 48 h, but not exceeding 72 hours of sealing the room.	The optimum gas regime for the specific cultivars must be reached as quickly as possible thereafter, but within 7 days of sealing.
Important notes	Bon Chretien: • Can be handled after extended CA-storage, provided that only fruit of optimum maturity is stored and that the cold chain immediately after storage is strictly maintained. • Must be stored at 0% CO_2	
	Forelle: • Mature Forelle pears from certain areas are prone to CO_2 injury and should therefore be stored at 0% CO_2 if possible.	

MINIMUM STORAGE CONDITIONS	PRIMARY PRINCIPLE	ADDITIONAL INFORMATION
Loading of CA room	**Orchard run fruit**: loading should not exceed 7 days, during which effective cooling must take place.	
	Pre-sized fruit: loading may take up to 14 days from beginning of harvest. Minimum gas regimes must be reached within 7 days of sealing the room (total of 21 days from the beginning of harvest).	Effective cooling must take place during the loading period.
	Exception: where Packham's Triumph picked in week 7 is to be stored with Golden Delicious and/or the red cultivars picked in ± week 9. Under these conditions the total loading time of pears and apples should not exceed 21 days and minimum gas regimes (3% O_2) must be attained within 7 days of sealing the room.	The maximum number of days for the whole operation may therefore not exceed 28 days.
Temperature	RA and CA-storage: fruit must be placed under refrigeration within 24 hours from start of harvesting.	Core temperatures after sealing the room must be reached as follows: Bon Chretien: 2 days to 2°C + 2 days to -0,5°C (total 4 days) Other cultivars: 3 days to 2°C + 3 days to -0,5°C (total 6 days) To attain the above temperatures within the prescribed time limit, forced air cooling should be used.
Gas regimes	Prescribed gas regimes must be reached within 7 days of sealing the room.	

IDEAL STORAGE CONDITIONS	PRIMARY PRINCIPLE	ADDITIONAL INFORMATION
Temperature	Golden Delicious, Starking and other red cultivars to be cooled to a core temperature of -0,5°C within 48 hours of harvest and held at that temperature during storage. 2 recommended methods for handling Granny Smith: • cool to 3°C within 48 hours after harvest and hold at this temperature for 10 days. Then cool to -0,5°C as quickly as possible; or • cool to 0°C within 48 hours after harvest and then increase the storage temperature to +0,5°C for the duration of storage.	These methods should prevent core flush without yellowing of the apples.
Relative Humidity (RH)	Must be between 90% and 95%.	Applicable to RA and CA storage. It is difficult to measure relative humidity accurately, but most cold stores are designed to maintain a high relative humidity.
Gas Regimes (See Appendix 2)	**Nitrogen flushing**: attain a gas regime of 3% O_2 + 1,5% CO_2 within 48 h, but not exceeding 72 h of sealing the room. The CO_2 concentration must not exceed 2,5% during the pull-down period, except in the case of Golden Delicious where the CO_2 concentration may not exceed 5%.	The optimum gas regime for the particular cultivar must be reached as quickly as possible thereafter, but within 7 days of sealing.
	Nitrogen generator: attain a gas regime of 3% O_2 + 3% CO_2 within 48 h, but not exceeding 72 h of sealing the room. The CO_2 concentration must not exceed 2,5% during the pull-down period, except in the case of Golden Delicious where the CO_2 concentration may not exceed 5%.	The optimum gas regime for the particular cultivar must be reached as quickly as possible thereafter, but within 7 days of sealing.

MINIMUM STORAGE CONDITIONS	PRIMARY PRINCIPLE	ADDITIONAL INFORMATION
Loading of CA room	**Orchard run fruit**: loading should not take longer than 7 days, during which time effective cooling must take place.	
	Pre-sized fruit: loading may take up to 14 days from beginning of harvest, but it is required that the minimum gas regimes be reached within 7 days of sealing the room (total of 21 days from beginning of harvest).	Effective cooling must take place during the loading period.
	Exception: where Packham's Triumph pears picked in week 7 are to be stored with Golden Delicious and/or the red cultivars picked in ± week 9, the total loading time of pears and apples may not exceed 21 days and the minimum gas regimes must be attained within 7 days of sealing the room. Total 28 days for the whole operation	The maximum number of days for the whole operation may therefore not exceed 28 days.
Temperature	Place fruit under refrigeration within 24 hours from start of harvesting. Attain core temperatures after sealing the room as follows: **Granny Smith**: 4 days to 3°C + 10 days to -0,5°C or +0,5°C (minimum: -0,5°C, total 14 days) **Other apples**: 4 days to 2°C + 3 days to -0,5°C (total 7 days)	These guidelines are applicable to RA and CA storage.
Gas regimes	The following gas regimes should be reached within 7 days of sealing the room (i.e. within 14 days from start of harvesting) with reference to orchard run and presized fruit. Granny Smith 3,0% O_2 1,0% CO_2 Other cultivars 3,0% O_2 1.5% CO_2	Note: CO_2 levels should never exceed 2,5% to prevent possible damage to the fruit. The exception is Golden Delicious where the maximum CO_2 level can be 5%.

APPLES & PEARS	PRIMARY PRINCIPLE	ADDITIONAL INFORMATION
Interruption of CA storage	If CA conditions must be interrupted* a total period of 21 days (including pull-down period) above 2,5% O_2 may not be exceeded at any time. If this does occur, the fruit should not be regarded as CA-stored. Partially CA-stored fruit does not qualify as CA fruit, although the fruit will still benefit.	* e.g. due to partially packing a room for export or mechanical or other failures. ** E.g. stored in RA for longer than 14 days prior to CA storage.
Measuring of oxygen concentrations with portable O_2 analyser	Oxygen concentrations in CA rooms to be measured at least once weekly at the room itself with a portable analyser. This additional reading may be recorded on the log sheet or on a separate sheet.	This prevents the danger of alcohol formation because of faulty control equipment. This reading is additional to the existing control system where O_2 levels are measured at least twice daily and does not replace the traditional system. Record keeping of the measurements must form part of the existing record keeping process.
Tolerance	The maximum tolerance for gas concentrations for pears and apples are: Oxygen (O_2) + or -0,5% Carbon dioxide (CO_2) + or -0,5%	
Temperature range	Temperature ranges for the storage of apples and pears are: Minimum -0,5°C Maximum 1,0°C	
Minimum storage period	The minimum storage period under conventional CA conditions for pears and apples to quality to be CA fruit should be 60 days.	

APPLES & PEARS	PRIMARY PRINCIPLE	ADDITIONAL INFORMATION
Log sheet (See Appendix 3)	Computer printouts and standard log sheets may be used. The following basic information is needed to be monitored: • Air delivery and return temperature • Fruit core temperatures in the front and back of the room • Oxygen and carbon dioxide readings	All the information on the standard log sheet should also appear on the computer printout. This information should be recorded at least twice daily.
	The following important dates must be recorded: • Start harvesting • Start pre-cooling (if any) • Start of loading the room • Date of sealing the room	
Export fruit in CA storage	Pears and apples stored under CA conditions for export must be treated in the same manner as fruit for the local market, except for the dipping and drenching treatments.	Producers should apply the recommendations supplied by ARC Infruitec-Nietvoorbij and comply with the directions of the various manufacturers of dipping and drenching material.
Safety precautions	CA operators should be aware of the content of the safety procedures applicable to CA rooms.	

APPENDIX 1

RECOMMENDED GAS REGIMES AND STORAGE PERIODS FOR PEARS

Cultivar			O_2 (%)	CO_2 (%)	Temperature (°C)	Storage Period (months)	Alternatives to DPA
Bon Chretien	Opt.	:	1,0	0,0	-0,5	4	No
	Max	:	1,5	0,0	0,0		
	Min	:	1,0	0,0	-0,5		
Beurre Bosc	Opt.	:	1,5	1,5	-0,5	4	No
	Max	:	2,0	2,0	0,0		
	Min	:	1,0	1,0	-0,5		
P. Triumph	Opt.	:	1,5	2,5 or 1,5	-0,5	9-10	DCA; RLOS;
	Max	:	2,0	3,0	0,0		DCA+1-MCP after 180 d
	Min	:	1,0	1,0	-0,5		DCA pre-shipment
D. du Comice	Opt.	:	1,0	1,0	-0,5	6	No
	Max	:	1,5	1,5	0,0		
	Min	:	1,0	1,0	-0,5		
Forelle	Opt.	:	1,5	<1.0	-0,5	7	DCA or FEMA
	Max	:	2,0	1.0	0,0		
	Min	:	1,0	0,0	-0,5		
Josephine	Opt.	:	1,5	1,0	-0,5	8	No
	Max	:	2,0	1,5	0,0		
	Min	:	1,0	0,0	-0,5		
Rosemarie	Opt.	:	1,5	1,0	-0,5	5	No
	Max	:	2,0	1,5	0,0		
	Min	:	1,0	0,0	-0,5		
Flamingo	Opt.	:	1,5	1,0	-0,5	5	No
	Max	:	2,0	1,5	0,0		

Min :	1,0	0,0	-0,5		

RECOMMENDED GAS REGIMES AND STORAGE PERIODS FOR PEARS

Cultivar			O_2 (%)	CO_2 (%)	Temperature (°C)	Storage Period (months)	Alternatives to DPA
Abate Fetel	Opt.	:	1,5	0,5	-0,5	4	No
	Max	:	2,0	1,0	0,0		
	Min	:	1,0	0,0	-0,5		

APPENDIX 2

RECOMMENDED GAS REGIMES AND STORAGE PERIODS FOR APPLES

Cultivar		O_2 (%)	CO_2 (%)	Temperature (°C)	Storage Period (months)	Alternatives to DPA
Golden Delicious	Opt. :	1,5	2,5 or 1.5	-0,5	7-9	
	Max :	2,0	3,0	0,0		Alt: 1-MCP/DCA
	Min :	1,0	1,0	-0,5		
Granny Smith	Opt. :	1,5	1,0	0.0	11	Stepwise cooling
	Max :	2,0	1,5	+0,5		Alt: 1-MCP/DCA
	Min :	1,0	0,0	0.0		
Red Delicious	Opt. :	1,5	2,5 or 1.5	-0,5	9	
	Max :	2,0	3,0	0,0		Alt: 1-MCP/DCA
	Min :	1,0	1,0	-0,5		
Royal Gala	Opt. :	1,5	1,5	-0,5	Flavour: 3 months	Alt: 1-MCP/DCA
	Max :	2,0	3,0	0,0	Quality: 7 months	
	Min :	1,0	1,0	-0,5		
Cripps' Pink Rosy Glow	Opt. :	1.5	0.5	1.0	6-8	Stepwise cooling
	Max :	2.0	1.0	1.5		Alt: 1-MCP/DCA
	Min :	1.0	0.0	1.0		
Carmine	Opt. :	1,5	1,5	-0,5	7	Alt: 1-MCP/DCA
	Max :	2,0	3,0	0,0		
	Min :	1,0	1,0	-0,5		
Cripps' Red (Joya)	Opt. :	1.5	0.5	1.0	9	Alt: 1-MCP/DCA
	Max :	2.0	1.0	1.5		Stepwise cooling
	Min :	1.0	0.0	1.0		
Braeburn	Opt. :	1,5	1.0	-0,5	8	No
	Max :	2,0	1.5	0,0		
	Min :	1,0	0.5	-0,5		

Fuji	Opt.	:	1,5	0.5	-0,5	7-8	Alt: 1-MCP/DCA
	Max	:	2,0	1.0	0,0		See best practise protocols
	Min	:	1,0	0,0	-0,5		

DCA = Dynamic controlled atmosphere storage
RLOS = Repeated low oxygen stress

LOG SHEET

APPENDIX 3

ROOM NO.: **PICKING TIME: FROM ……………………….. TO ………………….** **PRE-COOLING TIME:** **(DAYS)**

Cultivar: **LOADING TIME:** **(DAYS)**

Date	Time	Gas mixture		Ambient Pressure	Ambient temperature (°C)	Cold room air temperature		Fruit core temperature (°C)		Defrosting time (min)	Oxygen at Room (hand held)	Signature	Remarks
		O_2 (%)	CO_2 (%)	(millibar)		Front	Back	Front	Back		(%)		

CHAPTER 7

CREATING AND MAINTAINING CA GAS REGIMES

A. C. Shultz, N. da Silva, D. Graham, W. Bayliss, J. S. Findlay

Summary

Once the CA room is filled with fruit and the doors have been sealed, the O_2 in the air remaining in the room is pulled down by dilution purging with N_2, from 21% to around 5%. The N_2 is commonly supplied in liquid form of by on-site N_2 generators. Respiration of the fruit in the CA store reduces the O_2 further, by converting it to CO_2.until the desired level (normally 1,5%) is achieved. When the O_2 drops below the recommended level, air is injected. If the CO_2 rises beyond the level recommended for the cultivar being stored (normally between 0% and 3%), it is removed, generally using activated CO_2 scrubbers or lime. Certain cultivars should be stored at CO_2 levels lower than 1%. In this case lime is used, as the activated carbon scrubbers are not effective at lower than 1% CO_2. Regular analysis of the CO_2 and O_2 in the store enables the gas regime to be controlled manually or automatically, by switching on a scrubber or injecting air.

PULL DOWN TO THE DESIRED O_2 LEVELS

There are three methods of bringing the O_2 level down to the desired level:

Method 1: Letting the fruit use the oxygen in the CA room until such time as the O_2 has reached the desired level.

This method unfortunately takes up to 28 to 30 days. The warmer the fruit, the more rapid the respiration rate. Deterioration also takes place during this long pull-down period. This method is no longer used in the CA industry.

Method 2: Flushing the store with liquid N_2.

This method is commonly used in South Africa today provided that the CA storage complex is close enough to a source of liquid N_2. Liquid N_2 is supplied by road tanker complete with vaporiser. Larger complexes have a stationary tank and vaporiser on-site which is filled with liquid N_2 when necessary from the road tanker.

The following is the standard method now used in the CA industry:

- Couple the flexible hose from the vaporiser to the 50 mm flange in the front wall of the room.
- Remove the top hatch in the roof of the room and start the fans. Build up tanker pressure to 14 bar.
- Commence flushing with inlet valve fully open.
- Start closing top hatch until a back pressure of 10 mm of water gauge is obtained (not more).
- Flush down to ±4% O_2 then disconnect the flexible hose and close the top hatch as quickly as possible.

A block of polystyrene should be positioned against the bin directly in front of the injection point, to prevent dehydration and possible freezer-burn of the fruit, or a spreader-pipe can be used to distribute the N_2 gas evenly.

The optimum flow rate into a 1 040 bin CA room is between 1000 and 1500 kg of N_2/hour.

It has been found that 1 kg of N_2/bin brought the O_2 concentration down to between 7% and 8% O_2; 1,5 kg of N_2/bin to between 5% and 6% O_2 and 2 kg of N_2/bin to ±4% O_2.

There will always be a slight increase in the concentration of O_2 (±0,5%) after flushing is completed due to final stabilisation of the O_2 level.

Trials have also been carried out to try to decrease the N_2 consumption by:

1. Increasing the back pressure in the room to 12,5 mm of water gauge, and even up to 25 mm of water gauge.

2. Altering the position of the N_2 injection point.

Both the above have a negligible effect on the N_2 consumption.

Quotes for the supply and flushing of N_2 should be obtained timeously from the suppliers in the off-season, and the supplier should always be given sufficient notice as to when a room or rooms are to be flushed. It is always more economical to flush more than one room at a time.

A saving in N_2 can be obtained by flushing from one room to another with the discharge gas. This requires the availability of the necessary pipes of very substantial size, which can be costly.

Method 3: On-site N_2 generators

Three types of N_2 generators are in common use in SA:

1. Nitrogen membrane separators force compressed air through hollow semi-permeable membrane fibres. The N_2 is less permeable through the side wall of membrane fibre than O_2 is and the N_2 concentration increases as the gas proceeds down the length of the membrane.

2. Vacuum Swing Adsorption (VSA) separates the N_2 and O_2 by preferential adsorption of the O_2 on molecular sieve beds. The molecular sieve beds are cycled between adsorption or regeneration using vacuum. The VSA equipment is generally connected to the room in a closed cycle to increase its effectiveness (compared to feeding the unit with fresh air). One VSA design, the combination O_2 and CO_2 scrubber, can be used for both the initial O_2 pull-down and also for CO_2 control for the CA storage period. The combination scrubber is described in more detail in the CO_2 scrubbing section below.

3. Pressure Swing Adsorption (PSA) also separates the N_2 and O_2 by preferential adsorption of the O_2 on molecular sieve beds. The molecular sieve beds are cycled between adsorption at high pressure and regeneration at ambient pressures.

The first N_2 membrane separator in SA was installed in 1994 and the first VSA in 1999. By 2005 more than 60% of the CA stores use N_2 from on-site generators for O_2 pull-down.

Powdered lime absorption

a) Direct placement of lime in the room:

One 12,5 kg bag of lime/bin is placed in the room on top of the bins, stacked 9 or 10 bins high (i.e. 9 or 10 bags are placed on top of the stack), either on a pallet or directly on the fruit, to maintain the CO_2 level at 0% for Granny Smith for the first 6 months of storage, gradually increasing to 0,5% - 1% over the next 3 months of storage as the lime is used and is converted from $Ca(OH)_2$ to $CaCO_3$

b) The external lime tent (Fig 5):

The external lime tent is made from heavy-duty vinyl and fits over the top of two pallets each carrying 80 x 12,5 kg bags of lime, high-grade $Ca(OH)_2$ with 45%+ available lime. The pallets (1,2 m x 1 m) are placed on bricks or on other pallets in a metal bath 3,2 m x 1,5 m x 200 mm deep, with a 40 mm piece of flat iron round the side of the bath for stability and strength. The pallets are placed side-by-side above the water with 5 bags of lime per layer (Fig 5), each layer being separated by three pieces of wooden dunnage, 40 mm thick. The pallets are stacked 20 bags high inside the external tent. The inlet and outlet pipes can be 75 mm diameter flexible pipe with sealed connections to the entries into the CA store. Pipes of

110 mm min diameter are preferable. The outlet is situated on the top of the tent in the middle with the inlet at the bottom, 150 mm above the water in the tank or

300 mm from the bottom edge of the tank. A small fan is used to suck the air from the top of the tent so that the tent sucks fast to the pallets of lime causing the atmosphere to pass through the bags of lime. The fan is a TDM.350 model from Luft or equivalent, moving 350 m^3/h of atmosphere.

It has been found that the lime in a closed passage or airlock lasts 15 to 21 days, depending on quality, while the lime in an open passage where there is wind and air movement, can last up to 30 days. No explanation has as yet been found for this.

A better absorption of CO_2 and longer lime life is achieved by wetting the paper bags of lime thoroughly while filling the water tank below.

c) **The internal lime tent (Fig 6):**

This is made of vinyl or nylon of slightly cheaper material than the external lime tent as it does not have to be so gas-tight. The gauge is 400-450 g/m^2.

Velcro is used to seal the tent onto the frame around the large door. Normally 60 x 12,5 kg bags of lime are placed on a pallet inside the internal lime tent, up against the suction outlet where the same type of fan, as used in the external lime tent, is installed, sucking the air through the pallet of lime. The 60 bags generally last 10 to 14 days and must be thoroughly wet prior to placing inside the tent.

The inlet to the tent is at the top on the far side from the suction outlet at the bottom. When the $Ca(OH)_2$ has become $CaCO_3$ and is saturated with CO_2 all fans are switched off, the main door opened and a forklift quickly removes the pallet of lime and replaces it with a new one. Very little, if any, rise in O_2 occurs when changing pallets in the CA store. Safety regulations when entering a CA store must at all times be observed.

d) A combination of a lime tent and activated carbon scrubbers can also be used.

Some hints on CO_2 absorption by means of lime scrubbing

When lime is used in the absorption process, it could happen that the results achieved are not always favourable. Although there may occasionally be deviations as a result of lime quality, this does not imply that lime suppliers are necessarily to blame when poor results are achieved.

When using lime, the following aspects should be noted:

1. It is a common practice to store more than one cultivar of fruit in the CA room. This results in an extended loading period. If lime is placed in the room with the first consignment, absorption will commence immediately due to the release of CO_2.

2. Usually, entries are only made in log records from the moment the room is sealed or when withdrawal of CO_2 commences. The recorded time in which the lime absorbs CO_2 appears brief and uneconomical, and the observation is that the good results of past seasons were no longer being achieved, not taking into account however, that part of the efficiency had already been utilised before record-keeping.

3. Fruit may not be pre-cooled before placing in CA stores, as in the past. Warm fruit respires much faster than cold fruit and consequently also releases CO_2 much faster, which, in turn, converts the lime from $Ca(OH)_2$ to $CaCO_3$ much faster.

4. Fruit maturity can be a contributory factor in determining the respiration tempo which, in turn, could affect the life expectancy of the lime.

5. Lime should be stacked in such a way, that the maximum surface area of the lime is unobstructed to facilitate contact with the CO_2. Bags should preferably be packed flat on well-ventilated wire racks or similar equipment.

6. Lime placed in tents or similar receptacles often do not fill the total volume of space available, with the result that an airflow throughway is created.

7. Faulty placing of lime can cause air which must flow through the tent, to be caught up in a whirlpool, impeding an effective interchange of air to the lime.

8. Stacking, of bins must be done in such a manner that it does not obstruct the flow of air to the lime or other type of scrubber.

9. Problems can occur where cooling fans are rear-mounted and the lime tent is placed in front of the door, with a couple of bins cross-stacked, to maximise available space.

Although the CO_2 filled air will make contact with the lime, the interchange of air will not be fully effective.

10. The preliminary amount of lime placed in a room to control the initial production of CO_2 varies with a method of O_2 attainment, i.e. N_2 flushing or fruit respiration. Experience is the best judge of the actual amount of lime to be placed in a room.

Activated Carbon Scrubbers

An activated carbon scrubber should be capable of holding the atmosphere at 1% $C0_2$ without introducing significant quantities of O_2. The rooms should also be filled with a loading density of 250 kg/m^3. Certain types of scrubber design require the rooms to be equipped with breathing bags for the compensation of the depression caused by the cooling plant. Calculations for CO_2 generation and adsorption are normally based on 5 kg/24 h/l 000 bin room. This could be on the low side, especially if the fruit is respiring at higher temperatures. These calculations are for fruit at -0,5°C. For orchard run fruit or for storage at higher temperatures, the CO_2 evolution can be two or three times higher than at -0,5°C.

The CO_2 scrubbing capacity is proportional to the CO_2 level to be maintained in the CA store. To maintain the CO_2 at 1.5% requires an activated carbon scrubber with twice as much capacity as if the store was maintained at 3% CO_2.

Combination O_2 and CO_2 Scrubbers

Introduced in 1999, combination O_2 and CO_2 scrubbers use VSA (Vacuum Swing Adsorption) technology to adsorb the initial O_2 from the air in a CA store and can also be used to remove the CO_2 produced by the fruit. Combination O_2 and CO_2 scrubbers are cost effective for smaller CA facilities (up to 4 000 bins CA capacity) where liquid N_2 is expensive or not available. Due to the high cost of the molecular sieve adsorbent which requires periodic replacement the Combination Scrubber is expensive to operate for long term CO_2 control with more than approx. 4 000 bins CA. For larger facilities or when the facility grows it is generally more economical to install a dedicated activated carbon CO_2 scrubber and use the combination unit only for the initial O_2 pull down.

Continuous purging with N_2 generated on site

In South Africa, a number of CA stores use on site N_2 generators for the initial purge to decrease the O_2 in the store. There are 2 types of generators in common use: N_2 separators based on semi-permeable membrane technology and VSA (Vacuum Swing Adsorption) using molecular sieve technology.

Even if the capital cost of this type of equipment is covered for the initial N_2 purging needs, the operating costs of on-site generators (electricity for the N_2 Separator and replacement molecular sieve for the VSA) substantially exceed the capital and operating costs of an equivalent activated carbon scrubber.

In emergency on-site generated N_2 or liquid N_2 could be used for CO_2 control.

Cost of Various Scrubbing Methods

No cost comparisons can be given here due to the continuous changing of interest rates as well as the value of our local currency, resulting in discrepancies over short periods of time.

The following facts may be of assistance in reaching decisions:

1. Around 95% of the industry is controlling CO_2 with activated carbon scrubbers. Lime scrubbing is used for approximately 5%.
2. Rapidly rising cost of labour in our industry for lime removal and disposal.
3. Trustworthy automated control systems, that will give accurate control of CO_2 levels at acceptable cost levels, are available.
4. The costs of liquid N_2 and cryogenic transport have increased considerably over the last few years.
5. When HACCP or any equivalent accreditation is required, check their applicable requirements.

Gas Analysing Equipment

During the early years all CA stores started with an Orsat gas analyser. In the 2005 season it is reasonable to assume that no measurements were made with this instrument.

A number of electronic analysers are available in the market for measuring both O_2 and CO_2. The gas analysers always need to be regularly checked (or calibrated) either against a bottle of known gas concentration or against the normal atmosphere. Also the integrity of the total sampling system should be checked weekly with a handheld O_2 instrument, with a sample taken directly from the CA store. These gas analysers were usually read and recorded twice a day by the CA operator, and the O_2 and CO_2 in the room adjusted manually by switching on a scrubber for the CO_2 and letting ordinary air into the room if the O_2 had dropped too low. Fortunately in South Africa, most CA rooms are extremely gas-tight and consequently normally require that O_2 be bled into the room rather than having to find a means of lowering the O_2 level through using a gas generator

Most CA complexes have now adopted total recording and control through computerised instrumentation, with the gas analysis integrated into the system. There are a number of systems available which are all worth investigating for their cost-effectiveness, be they from Britain, Italy, or the local South African unit. This sophisticated equipment can normally record the temperature, O_2 and CO_2 hourly and also control the O_2 and CO_2. This is achieved by doing the analysis once every hour and opening the small O_2 inlet and outlet solenoids for air injection and starting and stopping either the lime scrubber or the activated carbon scrubbers to control the CO_2. With this type of sophisticated equipment it is possible to control the O_2 and CO_2 within 0,4% of the desired gas regime and to both have a print out and an electronic record of the data.

When installing this type of equipment, it is always well worth paying a visit to a complex where the equipment is already in use.

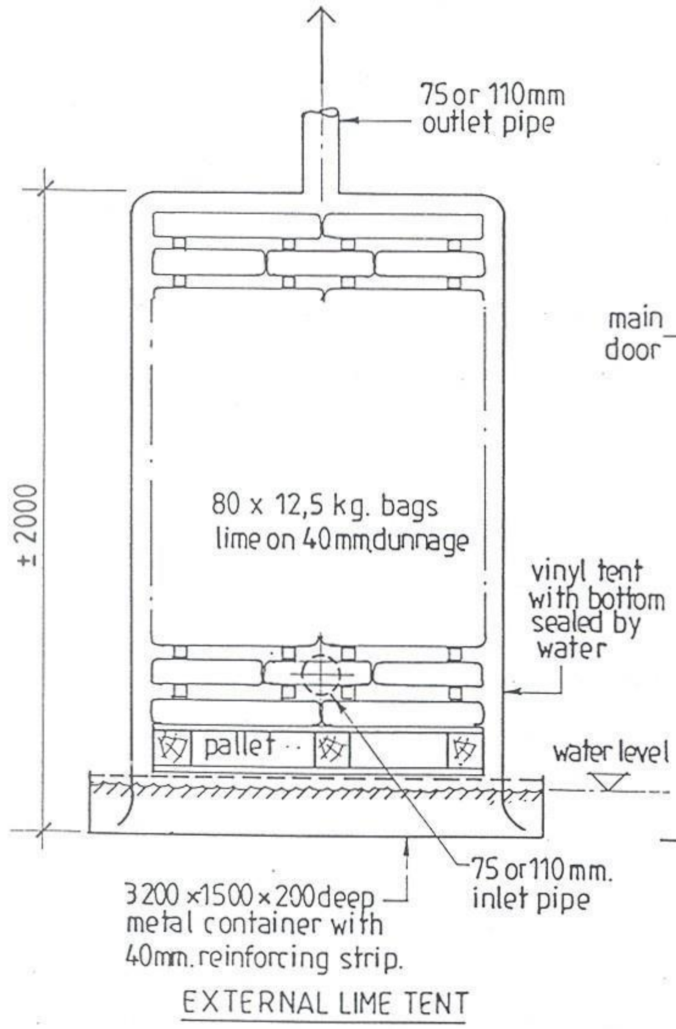

Figure 5. Diagram showing external lime tent

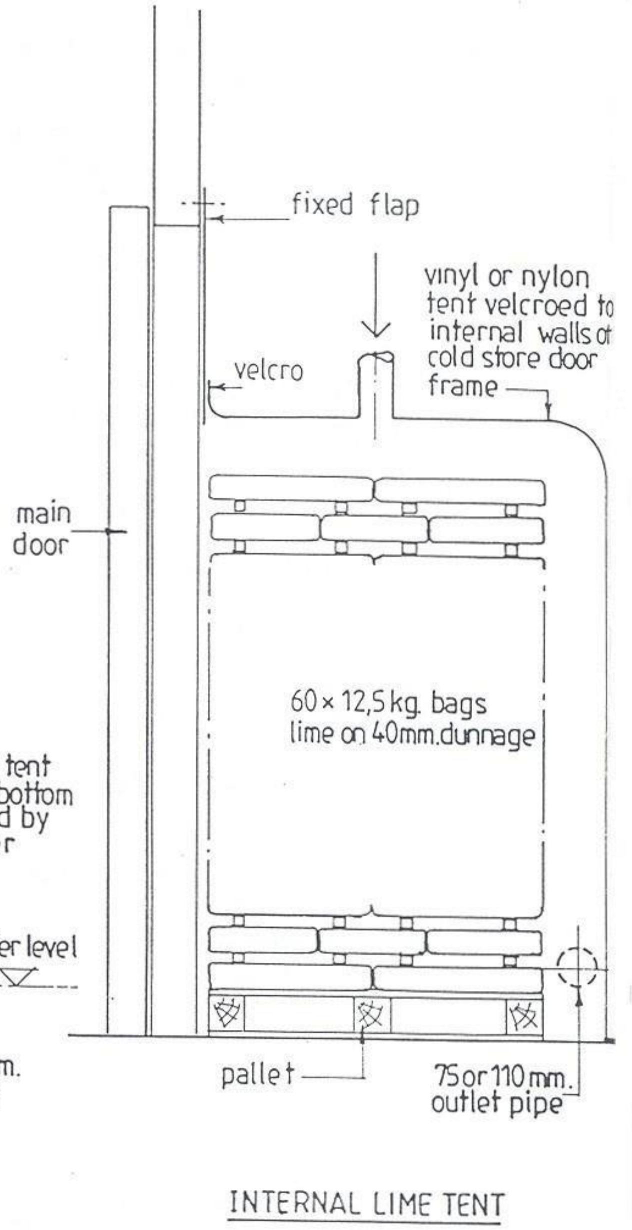

Figure 6. Diagram showing internal lime tent

CHAPTER 8

THE CONTROL OF POST-HARVEST DISORDERS DURING CA STORAGE

J C Combrink, A B Truter, J A van der Merwe, F Vries

INTRODUCTION

Quality maintenance during CA storage largely depends on the control of post-harvest disorders. However, the control of post-harvest disorders does not begin after harvest. It is an integrated process which starts early in the orchard. A fruit must be produced under conditions which enables it to resist post-harvest disorders. This general rule applies to both physiological and microbiological disorders. All the pre-harvest factors which play a role in the development of post-harvest disorders will not be discussed in detail, but it is essential to mention them briefly. However, factors which play a significant role will be discussed. Control of post-harvest disorders is preceded by optimal production practices. Factors which play a significant role in the development of post-harvest disorders include too little or too much fertiliser, too much irrigation water, the stage of fruit maturity, and handling of fruit during and after harvest. In large cooperatives, where different persons are responsible for production and post-harvest handling, close liaison between the pre- and post-harvest components is essential. The pre-harvest component must at all times be aware of the requirements of the post-harvest component regarding fruit quality. The post-harvest component must also be acquainted with the factors which affect fruit quality during production. Climate can affect fruit quality considerably. If abnormal weather conditions occur during the season, the cold store operator must take cognisance and adjust his post-harvest strategy accordingly. It can therefore not be said that the cold store operator alone is responsible for the control of post-harvest disorders and the post-storage quality of fruit. Everyone involved in theproduction of fruit has a role to play. If everybody involved knows his role and plays his part, losses due to post-harvest disorders need not be significant. It requires a thorough knowledge of the disorders, their symptoms and factors which affect their development and methods to control them. An important factor is that the experts should be consulted in cases of uncertainty. Erroneous deductions, or incorrect perceptions about post-harvest disorders, can lead to confusion and result in unnecessary losses. The true extent of post-harvest losses is not readily appreciated. It involves a lot more the than the loss of the fresh product, and estimates are frequently too low because all aspects are not taken into account. In England and the USA, it is estimated that 50% of post-harvest losses of apples occur during cold-storage and 29% during transport and marketing. It is difficult to determine the extent of post-harvest losses accurately since factors which are difficult to quantify are involved. The value of the fresh product can be determined, but what must be borne in mind is that the value of the processed product, such as canned Bon Chretien pears, for example, is considerably higher than the value of the fresh product. Production costs, such as the pro rata price of the land, establishment of the orchard, pruning, chemicals, fertilisation, etc., must also be considered. Costs incurred after harvest, such as harvesting, transport and storage costs cannot be ignored. Any defect which a consumer sees on a fruit leads to loss of consumer confidence and this has an effect on subsequent sales. It is difficult to determine the extent of the loss of consumer confidence, but it is nevertheless significant. Once the consumer has lost confidence in a particular brand or cultivar, it may take more than one season to restore. If post-harvest losses are viewed in this light, its control will receive high priority.

PHYSIOLOGICAL POST-HARVEST DISORDERS

SUPERFICIAL SCALD

Symptoms

Superficial scald is a physiological abnormality which develops in the skins of some cultivars as a result of oxidative processes occurring at low temperatures during storage of immature fruit, or fruit which is physiologically under-developed (11). It is seen as brown discolouration of the skin and can vary in intensity from light to dark brown. Superficial scald mostly occurs superficially and detracts from the appearance of the fruit (27). In extreme cases, the cells below the cuticle are also affected (18). It is regarded as the most serious post-harvest disorder of apples.

Factors affecting the development of superficial scald during cold storage

Stage of maturity:

Superficial scald developed on 86,6% to 96,5% of Starking apples harvested between 116 to 129 days after full blossom (DAFB) (34). One week later, 138 DAFB incidence decreased to 20,7% and was subsequently less than 3%. The same trend was, observed in Granny Smith apples (17). Stage of maturity therefore has an effect of development of superficial scald. Apples picked before the optimum stage of maturity contain less anti-oxidants than those picked at the optimum stage (1). Such apples develop superficial scald during storage.

Temperature:

The development of superficial scald is related to temperature. Superficial scald only develops at temperatures below 4,5°C (17, 27) and cold storage therefore plays a significant role in the development of superficial scald.

Days before storage:

If storage of fruit is delayed or stored at temperatures between 0°C and 4°C the incidence of superficial scald can be high (15, 17). However, delays only have a small effect on the incidence of superficial scald on Granny Smith apples.

Duration of the cold storage period:

The longer the cold storage period, the higher incidence of superficial scald (15).

Cultivar:

Cultivars differ with regard to their susceptibility to superficial scald (12, 13). Granny Smith is the most susceptible of the South African-grown cultivar followed by Starking and other Red Delicious types. Golden Delicious occasionally develops superficial scald. Superficial scald also develops on Packman's Triumph pears. The scald which develops on Bon Chretien pears, is a senescent disorder unrelated to superficial scald.

Season:

The incidence of superficial scald varies from season to season (21, 36). Cool weather before harvest makes apples less susceptible to superficial scald, but if it is followed by dry, warm weather fruit may become more susceptible (17).

Control of superficial scald

1. **Chemical control:**

Keep in mind that certain markets do not accept fruit treated with Diphenylamine (DPA). DPA is an anti-oxidant generally used to control superficial scald (29). Correct application of DPA is extremely important and guide-lines on its application must be meticulously followed (12). The following concentrations of a 31% active ingredient diphenylamine product are recommended:

Granny Smith:	2 500 ppm
Fuji:	2 500 ppm
Red Delicious types & Packham's Triumph:	2 000 ppm
Pink Lady	1 000 ppm
Sundowner	1 000 ppm
Golden Delicious:	500 ppm

These concentrations can be decreased if apples are harvested at the optimum or post-optimum stage of maturity (36). However, general guidelines, applicable to all conditions, cannot be laid down because scald potential varies from season to season and conditions vary from farm to farm. The producer himself must therefore decide whether or not the DPA concentration can be lowered. His decision must be based on historical data on the scald potential of fruit from a particular orchard. Several factors are important during DPA application. The correct concentration for application must be maintained. The DPA concentration in the dump-tank must therefore be determined periodically using the available techniques (16). If water is added to maintain a constant volume, the correct amount of DPA must also be added. The amount of DPA required will be determined by the volume of water which is added. The DPA mixture must be replaced when it becomes dirty. Dust and fungal spores accumulate in the dump-tank decreasing the affectivity of the DPA and increasing the decay risk. When Red Delicious types are treated, the apples must be chlorinated and a fungicide added to the DPA mixture to prevent development of wet core rot. These treatments may have implications for marketing the fruit and producers must therefore decide beforehand for which market the fruit is intended. Some countries do not allow any post-harvest chemical treatment of fruit.

2. 1-MCP (SmartFresh^{SM})

1-Methyl-cyclopropine (1-MCP) mode of action is via a preferential attachment to the ethylene receptor, thereby blocking the effects of both endogenous and exogenous ethylene. It is applied in storage facilities and transit containers to slow down the ripening process and the production of the ethylene in fruit. Apples harvested at optimum maturity loaded in a gastight CA room cooled to -0.5°C and treated within seven days of harvest with 1-MCP by means of a special applicator, control scald for longer than 9 months in CA storage. Fruit treated with 1-MCP are superficial scald free, has excellent firmness and skin colour retention with an extended storage life and shelf-life of up to 14 d at 20°C. Research is in progress to optimise the technique for application on pears.

Manipulation of cold storage conditions:

Local and overseas research indicates that manipulation of cold storage conditions significantly decreases or even eliminates the need for treatment with anti-oxidants (2, 19, 20, 22, 23, 28, 32, 33).

1. **Initial Low Oxygen Stress (ILOS).**

Conditioning of Granny Smith apples at low O_2 concentrations during the first 10 days after the CA store has been sealed, followed by storage at ultra-low O_2 concentrations, decreases the incidence of superficial scald without DPA application. O_2 is flushed from the cold store with liquid N_2 at a temperature of 5°C until it reaches a concentration of 4%. The temperature is kept at 5°C to maintain a high rate of respiration which ensures that the O_2 is rapidly removed from the storage atmosphere. When the O_2 concentration reaches 0,5%, the temperature is decreased to 0°C. After 10 days, the O_2 concentration is increased to 2,5% over a period of 2 days and immediately thereafter decreased to 1,5% over a period of a further 2 days. A CO_2 concentration of 1% is maintained throughout. During the remainder of the cold storage period, which can be as long as 7 months, gas concentrations of 1,5% O_2/1,0% CO_2 are maintained. The best results are obtained with apples harvested slightly later than the optimum stage of maturity. The optimum harvesting period of Granny Smith can be as long as 3 weeks (35) and a considerable volume of fruit can be treated with this technique.

2. **High Temperature Pre-conditioning.**

Topred apples, harvested at the optimum stage of maturity and treated with 16% CO_2 for 10 days immediately after harvest, do not develop superficial scald during a storage period of 6 months at 1,5% O_2/1,5% CO_2. However, if the storage period is increased to 8 months the apples have to be treated with 500 ppm DPA.

3. **Dynamic Controlled Atmosphere Storage.**

Normal CA storage implements a safety margin in the oxygen concentration to eliminate the possibility of anaerobic respiration, which causes irreversible quality defects. Dynamic CA (DCA) is an improvement on conventional CA storage and consists of long term storage of fruit at O_2

levels just above the low O_2 stress point (the concentration where anaerobic fermentation starts). The stress point is continually monitored using fluorescence technology. In this way the oxygen concentration can continuously be controlled just above the point of anaerobic respiration. It potentially offers the following benefits to industry. Research trials on the DCA storage technique for three successive seasons on Golden Delicious, Granny Smith and Topred apples as well as Forelle and Packham's Triumph pears could inhibit superficial scald for storage periods of 7 to 9 months, and provided additional quality benefits. The DCA storage technique can be used successfully on Forelle (6-8 months) and Packham's Triumph pears (7 - 9 months) as an alternative for DPA if managed correctly. Both cultivars stored at DCA conditions showed better retention of skin colour, firmness and eating quality than fruit stored at conventional CA conditions. DCA storage inhibited superficial scald and could be applied as an alternative for DPA.

CORE FLUSH

Core flush or internal browning, mainly occurs in Granny Smith apples (13). Affected tissue spreads from the seed cavity and is firm, moist and pink to light brown in colour. In an advanced stage, it is dark brown. The causes of core flush are not known. Development of core flush can be inhibited by cold storage at 0°C to 0,5°C (10, 25) and 0% to 1% CO_2 at an O_2 concentration of 1% to 1,5% (13, 33).

MICROBIOLOGICAL POST-HARVEST DISORDERS

FACTORS AFFECTING THE DEVELOPMENT OF POST-HARVEST DISORDERS

Effective control of post-harvest decay is the integration of different pre- and post-harvest practices which are continuously and correctly applied during production, harvesting and storage of fruit (26). It starts in the orchard and a thorough knowledge of the factors affecting decay is required. It enables the producer to implement strategies for the control of decay long before harvest in order to produce fruit which has a low superficial spore count and a degree of resistance to fungal infection.

Environmental conditions

Moist, wet weather and high temperatures promote fungal growth and infection. The probability of infection is especially high when fruit remains wet for long periods.

Spore load:

The fungi causing post-harvest decay can grow and multiply on dead organic matter. Many spores are produced and wind, water, or insects spread them to fruit. If there are many spores on a fruit at harvest, the chances that infection may take place are high. Spores on fruit surfaces are washed off when the fruit is hydro-handled and a high spore concentration gradually builds up in the water. This also increases the decay risk.

Stage of maturity:

Fungi require nutrients to grow and sporulate. A fruit contains all the necessary nutrients and is therefore an excellent growth medium for fungi. However, immature fruit also contain components which inhibit fungal growth and prevent infection (30). Most fruit are resistant to infection until shortly before harvest. As a fruit matures, it becomes soft and bruises easily. Bruised fruit are much more susceptible to decay than unbruised fruit.

Cultivation practices:

Fungi can survive over wintering in orchards on pruning or decaying fruit remaining in the orchard after harvest. Wind and rain can disseminate these spores to uncontaminated fruit during the following season (14). Spores can also be spread through direct contact between decayed and sound fruit in a bin. Hygiene in the orchard is therefore important. Too much fertiliser can decrease the natural resistance of fruit against infection (24).

Harvesting and handling:

Most fungi causing post-harvest decay are wound pathogens that can only penetrate fruit through skin breaks (7, 3 1). Poor and rough handling, which can cause bruising and injuries can increase the incidence of decay by creating entry points of infection.

Cold storage conditions:

Low temperatures slow down the growth of fungi causing post-harvest decay, but growth is resumed as soon as the fruit are transferred to a high temperature (31). Similar to fruit, fungi also require O_2 for respiration. Low O_2 and high CO_2 concentrations can inhibit, fungal growth, but the concentrations generally used for CA storage have a negligible effect (3). CA storage delays fruit ripening and a fruit retains its natural resistance to infection for a long time (30).

DEVELOPMENT OF POST-HARVEST DECAY

The structure responsible for the distribution of fungi is called a spore (31). Post-harvest pathogens can be classified into two groups depending on their means of fruit penetration. Some, such as *Botrytis cinerea*, can penetrate an uninjured fruit directly, but others (*Mucor piriformis, Penicillium expansum)* require a fresh wound and are referred to as wound pathogens.

A fungal spore settling on a fresh wound swells, germinates and forms a germ tube (31). Germ tube penetrates the fruit and if it can overcome the natural resistance of the fruit, it spreads and a typical decay lesion develops. The asexual life cycle of the fungus is completed when it sporulates on the decayed fruit. During hydro-handling after storage, these spores spread from decayed to sound fruit or fresh wounds and cause decay after packaging.

MOST IMPORTANT POST-HARVEST PATHOGENS AND THE DECAY THEY CAUSE

Decay developing during CA storage is mostly caused by four fungi (13):

Alternaria-rot *(Alternaria alternata)*

A round, dry lesion, usually dark brown to black in colour is characteristic of decay caused by this fungus. It is usually associated with wounds. Dark fungal growth covers the lesion under moist conditions.

Blue mould rot (*Penicillium expansum*)

Infection occurs through wounds. Decayed tissue is light-brown, very watery and can be separated completely from healthy tissue. In advanced stages of decay, lesions are covered by blue-green spore masses. Spores washed into open calyx tubes during hydro-handling can cause wet core rot.

Mucor rot *(Mucor piriformis)*

Small, brown lesions rapidly increase in size and the fruit is completely decayed within two days. The skin of a decayed fruit has a parchment-like texture and does not break easily. Decayed tissue is very watery. Spores are produced at skin breaks and at the stem and calyx ends of the affected fruit. Spores washed into open calyx tubes during hydro-handling can cause wet core rot.

Grey mould rot (*Botrytis cinerea*)

Infection takes place through the unbroken skin or through skin breaks. Decayed tissue is slightly moist and spongy. The skin of affected areas readily slips away when slight pressure is applied. At a high relative humidity the fungus produces grey spore masses on affected tissue.

CONTROL OF POST-HARVEST PATHOGENS

Orchard Hygiene:

Decay develops after a fungus spore has infected a fruit. The number of fungal spores present on the surface of a fruit determines the extent of the decay and to it, some extent also the rate at which it develops. If there are only a few spores on the surface of the fruit, the chances that decay will develop are small. The most important control measure is to reduce the spore load.

Reduction of the spore load must begin in the orchard before harvest. Decayed fruit and pruning, which provides nutrients for fungi, must be removed. Fungal spores produced by fungi on dead twigs or decayed fruit on the orchard floor spread to fruit on the tree or to adjacent roads. When fruit are transported on these roads after harvest, spores in the dust are transferred to fruit.

Post-harvest hygiene:

Fungal spores which have been deposited on fruit in the orchard or during harvest, can spread to clean fruit and wounds during hydro-handling and can cause decay. These spores must be removed before hydro-handling or cold storage. Chlorine is the most effective disinfectant for this purpose (8). Chlorine gas, calcium hypo chlorite or sodium hypo chlorite can be used. The best results are obtained when bins of fruit are treated immediately after harvest with 75 to 100 ppm available chlorine using enough water to thoroughly wet all fruit (6). Quaternary ammonium compounds e.g. Sporekill or Terminator can be used to sanitise hard surfaces.

Fruit can be treated with DPA after the chlorine treatment, provided sufficient draining time is allowed to prevent the chlorine from inactivating the DPA.

Before grading and packing, chlorine can also be used to kill spores washed from decayed fruit during hydro-handling. A concentration of 25 ppm available chlorine kills spores effectively (7, 8, 9).

Disinfection of containers and cold stores:

Cold stores (4) and bulk bins (5) are sources of fungal inoculum. Regular disinfection is therefore required. Cold stores can be disinfected with chlorine or a registered fungicide when fungal growth on walls is evident (3). Decay and dry fruit tissue adhering to bulk bins must be removed before disinfection as spores occur in high numbers on this tissue. Hot water applied under pressure (200 bar) effectively removes dust and spores from small cracks in the wood as well as most of the decayed tissue.

Conveyors in packsheds must be regularly disinfected, preferably daily, with a broad spectrum disinfectant such as chlorine. Disinfectants, which can taint the fruit or are phytotoxic, such as formaldehyde, must be avoided.

Chemical control of post-harvest decay:

To confirm further information regarding relevant fungicides registered for post-harvest use on apples and pears, refer to the most current **Industry Guideline Information on Restrictions on the Use of Plant Protection Products on Deciduous Fruit, on the HORTGRO website** (www.hortgro.co.za)**.**

CONCLUDING REMARKS

The control of post-harvest diseases during CA storage is an integrated process which starts in the orchard and is continued during and after storage. The control of physiological and microbiological disorders cannot be separated. Factors such as the stage of maturity and cooling rate, affects the development of both during cold storage. Low temperatures must be maintained after storage to decrease the rate of physiological deterioration and decay. If the post-storage phase is ignored, all efforts before harvest and during storage would be in vain.

Resistance in certain countries towards the use of post-harvest chemicals has led to great emphasis being placed on integrated fruit production. It is therefore important to produce healthy fruit with a long storage life which can be stored for extended periods without, or with the minimum use of chemicals. Factors which affect the development of post-harvest disorders must be borne in mind when CA storage is considered. Correct fruit handling and cold storage are extremely important. If control measures are conscientiously applied, losses due to post-harvest disorders will be minimal.

Editor's note.

A manual compiled and revised by South African experts Ester Lotz, Kobus van der Merwe and Selma Rogalska details the symptoms, causes and control of the most common physiological and microbiological post-harvest disorders encountered in pome and stone fruit during storage. It is well worth consulting. The manual entitled 'Manual for the Identification of Post-Harvest Disorders of Pome and Stone Fruit" can be ordered from ARC-Infruitec-Nietvoorbij, Private Bag X5026, Stellenbosch 7599, South Africa.

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CHAPTER 9

HEALTH AND SAFETY PROCEDURES FOR CONTROLLED ATMOSPHERE STORAGE.

H Lategan

Introduction

The atmosphere inside controlled atmosphere rooms under controlled conditions cannot sustain life. The oxygen, nitrogen and carbon dioxide ratio maintained inside the room will result in almost instant death for anyone entering without efficient protection. (See Annexure 1 for the effects of exposure to oxygen deficient environments.)

These rooms fall within the definition of a confined space in terms of the General Safety Regulations of the Occupational Health and Safety Act and the requirements set by Regulation 5 – Work in confined spaces, will then apply in full. (See Annexure 2 for a copy of the regulation and Annexure 3 for a schematic layout thereof.)

The operation of these rooms should be such that entrance should be strictly controlled and all entrances / exits should be locked. The operation should ideally be planned that entry under CA conditions as far as possible is prevented. If entry is really necessary, for taking samples or replacing lime, it should only be done according to the procedures as described in this document. To eliminate entry to CA stores, it is recommended that scrubber systems be used to control CO_2. Furthermore, samples can be prepared in advance in netbags (e.g. onion pockets) with an attached rope for removal from a safe distance outside.

It should also be taken into consideration that fruit "lives" and therefore also uses oxygen. Low oxygen levels can develop when large rooms are loaded slowly. Good ventilation will then be essential to ensure safety during the loading process.

SAFETY EQUIPMENT:

- 3 Self- contained positive pressure breathing sets each equipped with a 6 litre 300 bar pressure cylinder.
- 1 Resuscitator as required by General Safety Regulation 5 and ready for use in any emergency.
- 1 Emergency siren (Aerosol type recommended)
- 3 Safety ropes and harnesses.
- 3 Torches in good working condition.
- 1 Portable oxygen deficiency monitor.

PROCEDURES

1. SEALING OF THE CA ROOM.

1.1. Ensure that the room is loaded correctly.

1.2. Ensure that all personnel vacate the room.

1.3. Apply the sealing compound to the seals of the doors.

1.4. Close all doors, including the top hatch.

1.5. Lock all doors with good quality locks, including the top hatch.

1.6. Ensure that the keys to the locks are kept in a secure place that is not accessible to unauthorized people.

1.7. Display the necessary signs indicating that it is an oxygen deficient atmosphere and may only are entered by authorized personnel wearing self-supporting breathing apparatus, on all entrances.

2. MAINTAINING CA CONDITIONS IN THE COLD ROOM.

2.1. The displacing of the oxygen in the CA room can be done by blowing in nitrogen from an external bulk tank or nitrogen generator or similar system/method until the prescribed CA conditions are reached.

2.2. The CA rooms are to be monitored constantly to ensure that the prescribed CA conditions are maintained.

2.3. Carbon dioxide levels can be maintained with lime or through the use of a scrubber system. The latter system is recommended.

2.4. The CA rooms are to be physically inspected on a daily basis or at the change of shift to ensure that all the doors are locked.

3. PRECAUTIONS TO BE TAKEN BEFORE ENTERING CA ROOM.

All actions for the entry of a CA room are to be taken by or under the direct supervision of a trained person appointed in writing as the responsible person for the stores.

The following procedures are to be followed to ensure that the equipment is in a good serviceable condition:

3.1. SELF-CONTAINED BREATHING APPARATUS.

3.1.1. Check that the equipment is in a good and clean condition, complete and connections secure.

3.1.2. Check that the breathing valve lever is closed.

3.1.3. Open the cylinder valve and check that there is a full air charge in the cylinder. Note the cylinder pressure in the logbook (minimum pressure 270 bar). Close the valve on the cylinder and check that the cylinder pressure gauge does not drop more than 10 bar in 5 minutes.

3.1.4. Put on the breathing set. The responsible person must check that the correct procedure as followed.

3.1.5. While breathing normally, test the warning whistle by closing the cylinder valve. The whistle must activate when the pressure falls to +/− 55 bar. If the whistle functions properly, open the cylinder valve again.

3.1.6. Ensure that the mask fits properly and works under positive pressure. The escaping air when inserting two fingers between the face and the mask will be a good test.

3.1.7. All the operators and the standby must do the same as above.

4. PROCEDURE FOR ENTERING A CA STOREROOM UNDER CA CONDITIONS.

This procedure should be followed for all operations, which necessitates the entry of a cold room under CA conditions. For example, inspections, taking or removing samples, maintenance, or similar operations.

4.1. Obtain the authorization permit specifying the conditions and instructions for entry from the responsible person (Annexure 4).

4.2. Only those persons properly trained as whose names are specified on the permit, may enter the room.

4.3. The team for entry should always be three persons : two for action inside and the third on standby immediately outside the room. All three should be fully equipped with the tested breathing apparatus.

4.4. Ensure that a fully equipped resuscitator and at least one person trained in the use thereof are available outside the room.

4.5. Switch off the fans and switch on the lights before entering. If the lights do not work, all three persons should be equipped with torches tested for proper functioning.

4.6. The persons entering must be equipped with safety harnesses and lifelines to the standby outside the room.

4.7. The three persons should stay in sight of each other at all times.

4.8. Under no circumstances will anybody be allowed to climb onto a stack.

4.9. If for any reason the low-pressure alarm of the breathing apparatus sounds, the room must be vacated immediately.

4.10. After the work is completed inside the room, ensure that the room is vacated and switch off the lights.

4.11. Ensure that the door(s) are closed and properly sealed and locked and the warning signs clearly visible.

4.12. Ensure that the equipment is properly taken care of and pressure cylinders refilled or sent for refilling. All breathing apparatus sets are to be inspected and tested at intervals not exceeding 3 months.

4.13. Ensure that all the details of use, refills and inspections of the breathing equipment are logged in a register kept for each set.

4.14. Sign off the entry permit to indicate that the specified task is completed and ensure that these permits are filed for a period of at least 3 years.

5. PROCEDURE FOR THE VENTING OF THE COLD ROOM BEFORE UNLOADING.

5.1. Switch off the fan units.

5.2. Place warning notices for low oxygen levels and unauthorized entry at both ends in the lower passage.

5.3. Open the top hatch first. A second person present as a standby.

5.4. Then open the lower hatch in the presence of the standby. Ensure that nobody is exposed to possible oxygen deficient air. If any such situation is foreseen, use the prescribed breathing sets.

5.5. If the lower door ends in a passage, prohibit entry to the passage while the room is being ventilated. The most efficient way will be to close the ends of the passage with a safety gate or gates, which will allow efficient venting but prevents entry. If the door leads to the outside, a safety gate, which will allow efficient venting but prevents entry will be the best option.

5.6. Switch on the fan units and monitor oxygen levels.

5.7. When a safe oxygen level is registered the main doors can be opened.

5.8. Use the portable oxygen monitor to double check the oxygen level to ensure that it is safe.

5.9. Certify that the room is safe on a permit that allows entry to the room (Annexure 5).

6. EMERGENCY PROCEDURE.

6.1. If any person shows any signs of exposure to low oxygen levels, immediate action should be taken which will include: remove person(s) to a safe place, sound the alarm and apply oxygen resuscitation. Medical assistance must be summoned.

6.2. Emergency contact numbers must be available.

6.3. Nobody may enter a CA room which was not properly vented, not even for emergency action, unless he wears the prescribed breathing protection and follows the procedures.

6.4. Any incident which leads to unconsciousness, irrespective of the duration, must be reported to the inspector of Department of Labour immediately. Refer to Section 24 of the Occupational Health and Safety Act – Act 85 of 1993 as amended.

OXYGEN DEFICIENT ATMOSPHERES

22 %	**Oxygen enriched – high fire risk.**
21 %	
20 %	**Minimum for human safety.**
19 %	
18 %	
17 %	
16 %	
15 %	
14 % 13 % 12 %	**Respiration deeper, pulse rate increased, co – ordination poor.**
11 % 10 %	**Respiration faster and shallow, giddiness, poor judgement, lips blue.**
9 % 8 %	**Nausea, vomiting, unconsciousness, ashen face. 8 minutes exposure :- 100 % fatal, 6 minutes exposure :- 50 % fatal.**
6 %	
5 %	
4 %	**Coma in 40 seconds, convulsions, respiration ceases, death.**
3 %	
2 %	
1 %	
0 %	**Coma in 10 seconds, death.**

Table 6

Occupational Health and Safety Act

Act 85 of 1993

General Safety Regulation 5 : Work in confined spaces.

(1) An employer or user of machinery shall take steps to ensure that a confined space is entered by an employee or other person only after the air therein has been tested and evaluated by a person who is competent to pronounce on the safety thereof, and who has certified in writing that the confined space is safe and will remain safe while any person is in the confined space, taking into account the nature and duration of the work to be performed therein.

(2) Where the provisions of subregulation (1) cannot be complied with, the employer or user of machinery, as the case may be, shall take steps to ensure that any confined space in which there exists or is likely to exist a hazardous gas, vapour, dust or fumes, or which has or is likely to have, an oxygen content of less than 20 percent by volume, is entered by an employee or other person only when -
(a) subject to the provisions of subregulation (3), the confined space is purged and ventilated to provide a safe atmosphere therein and measures necessary to maintain a safe atmosphere therein have been taken; and
(b) the confined space has been isolated from all pipes, ducts and other communicating openings by means of effective blanking other than the shutting or locking of a valve or a cock, or, if this is not practicable, only when all valves and cocks which are a potential source of danger have been locked and securely fastened by means of chains and padlocks.

(3) Where the provisions of subregulation (2)(a) cannot be complied with, the employer or use of machinery shall take steps to ensure that the confined space in question is entered only when the employee or person entering is using breathing apparatus of a type approved by the chief inspector and, further, that -
(a) the provisions of sub regulation (2) (b) are complied with;
(b) any employee or person entering the confined space is using a safety harness or other similar equipment to which a rope is securely attached which reaches beyond the access to the confined space, and the free end of which is attended to by a person referred to in paragraph (c);
(c) at least one other person trained in resuscitation is and remains in attendance immediately outside the entrance of the confined space in order to assist or remove any person or persons from the confined space, if necessary, and
(d) effective apparatus for breathing and resuscitation of a type approved by the chief inspector is available immediately outside the confined space.

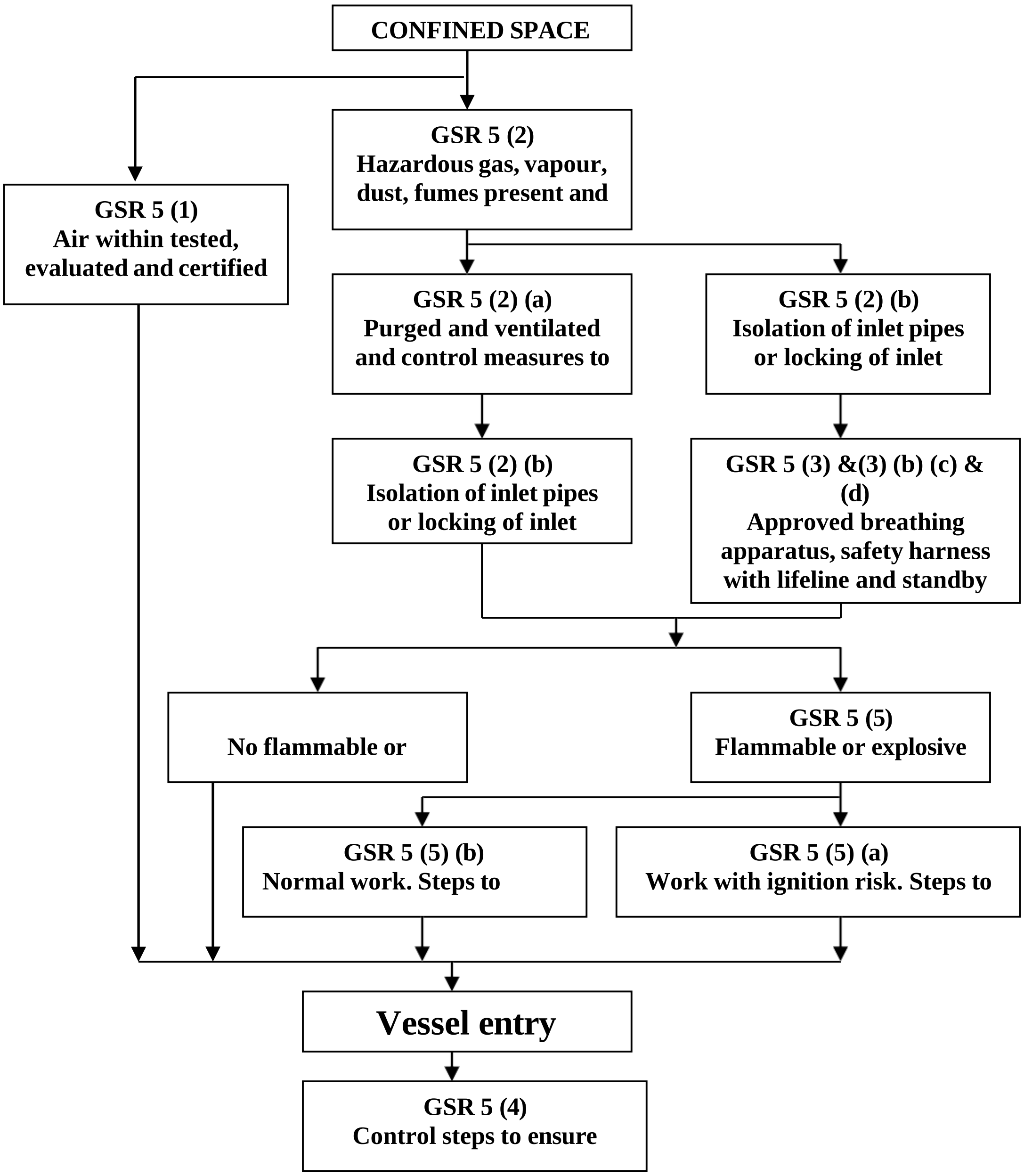
(4) An employer or user of machinery shall take steps to ensure that all persons vacate a confined space on completion of any work therein.

(5) Where the hazardous gas, vapour, dust or fumes contemplated in subregulation (2) are of an explosive or flammable nature, an employer or user of machinery shall further take steps to ensure that such a confined space is entered only if -
(a) the concentration of gas, vapour, dust or fumes does not exceed 25 per cent of the lower explosive limit of the gas, vapour, dust or fumes concerned where the work to be performed is of such a nature that it does not create a source of ignition, or
(b) such concentration does not exceed 10 per cent of the lower explosive limit of the gas, vapour, dust or fumes where other work is performed.

(6) The provisions of this regulation shall mutatis mutandis also apply, in so far as they can be so applied, to any work which is performed in any place or space on the outside of and bordering on or in the immediate vicinity of, any confined space, and in which place or space, owing to its proximity to the confined space, any hazardous article, oxygen deficient atmosphere or dangerous concentration of gas, vapour, dust or fumes may occur or be present.

Table 7

CONFINED SPACE ENTRY



DEFINTION OF CONFINED SPACE:

An enclosed, restricted or limited space in which, because of its construction, location or contents, or any work activity carried on therein, a hazardous substance may accumulate or an oxygen - deficient atmosphere may occur, and includes any chamber, tunnel, pipe, pit, sewer, container, valve, pump, sump or similar construction, equipment, machinery or object in which a dangerous liquid or a dangerous concentration of gas, vapour, dust or fumes may be present.

Table 8

ENTRY PERMIT: ROOM UNDER CA CONDITIONS

Date	
Complex No.	
Room No	

Responsible person :	
Operators :	
Task (s) to be done:	

Inspection
The following equipment is available and in good working order:

	Yes	No	N/A.	Signature
Breathing apparatus				
Alarm				
Flashlight				
Safety harness and -rope				
Radios				
Resuscitation equipment				
Standby personnel				

Certification

Herewith I,...as the responsible person, certify that the safety equipment is available and in a good working condition and that all the personnel involved are trained in the correct use of the equipment as well as the procedures and emergency procedures. All personnel are informed of the task that they must perform as well as the risks attached thereto.

Signature: ……………………………………………….

Date: ……………………………………. Time : …………………………………..

Table 9

PERMISSION: ENTRY OF CA ROOM

Date	
Complex No.	
Room No.	

Herewith I, ..., the appointed responsible person, declare that the room is properly vented, the air within tested and found safe for entry and that the necessary CA operators, forklift truck drivers and quality personnel may enter to perform their duties. I will retest the air quality on an hourly basis to ensure safety.

Time (measured hourly)							*Requirement*
Oxygen (%)							**> 20**
Carbon dioxide (%)							**< 0,5**
Carbon monoxide (ppm)							**50**
Sign							

Signature: …………………………………………..

Table 10

This information was researched, developed and published by Hammie Lategan

The Safety Network (Africa) CC.
Trading as:
SafeNet (Africa)
P O Box 1144
SANLAMHOF
7532

7 De Villiers Street
Bellville
7530

Tel : 021 946 1261
Fax : 021 946 1260
e-mail 1 : admin@safenetafrica.co.za
e-mail 2 : lategan@active.co.za
Website : www.safenetafrica.co.za

Consult OHS Act: General Safety Regulations, section 6
Work in elevated positions
No employer shall require or permit any person to work in an elevated position, no person shall work in an elevated position, unless such work is performed safely from a ladder or scaffolding, or from a position, where such person has made as safe as if he were working from scaffolding.

CHAPTER 10

MATURITY INDEXING AND MONITORING OF FRUIT QUALITY

R. F. Hurndall

INTRODUCTION

Apples and pears, grown under South African conditions of plentiful sunshine, are sought after on overseas markets because of their excellent taste and flavour. The harvesting of fruit at the correct stage of maturity plays an important role in eating quality.

The marketing of fruit should be conducted according to its storage potential. Maturity indexing is an integral part of the harvesting of apples and pears, both for export and long-term storage for the local market.

SAMPLING PROCEDURE

Fruit maturity varies between orchards, within orchards and within a tree. It is therefore necessary to monitor representative samples on an orchard basis in a pre-determined manner in order to select fruit for long-term storage.

This can be achieved by marking five trees per cultivar in an orchard and selecting one fruit of average size from each compass point of those trees. This will give a sample of twenty fruits. Where a particular cultivar is harvested selectively, it is important to choose samples which are representative of the following harvest, i.e. larger and/or well coloured fruit. Samples should be taken at shoulder height and at an arm's length into the tree. Samples should not be taken from exposed or densely shaded parts of the tree. Fruit with defects such as sunburn, core rot or insect damage should be avoided as these will influence fruit maturity.

Sampling should commence approximately 5 to 6 weeks before the intended harvest date in order to monitor the pattern of maturation. Sampling should take place on a weekly basis initially, while twice-weekly testing may be required to pin-point the optimum harvest date.

MATURITY TESTS AND INTERPRETATION

The following basic maturity tests are recommended:

Firmness

Fruit colour (green to yellow ground colour)

Seed colour (apples only)

Total soluble solids (measure of sugar content)

Starch conversion (apples only)

In addition, take note of the number of days after full blossom (DAFB), fruit size and weight. More sophisticated laboratories monitor fruit acidity as well.

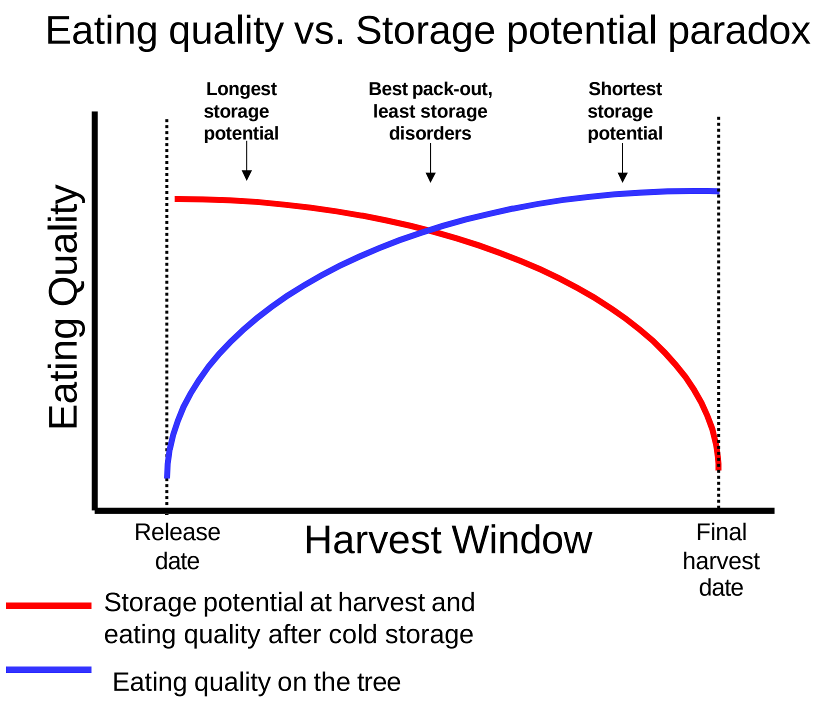


Figure 7 Eating quality versus storage potential paradox

The weather close to harvest as well as production practices influence the pattern of maturation. When interpreting results, it is necessary to consider a range of maturity indices as different combinations of indices signal the onset of ripening in each season. Furthermore, absolute values of each parameter vary from year to year. It is therefore necessary to monitor rates of change for each index in conjunction with absolute values.

The ***release date*** describes the start of the harvest window, and is the point where the fruit has reached physiological maturity. In other words, it will ripen to good eating quality after a period of storage. In the case of Golden Delicious and the red varieties, the harvest window per orchard usually lasts approximately 14 days, while a 21-day period is found in cultivars such as Packman's Triumph and Granny Smith. Fruit harvest before the release date will be starchy and tasteless, and will be prone to bitter pit, wilting and superficial scald. Fruit harvested in the early part of the harvest window, will be more prone to bitter pit and superficial scald than later harvested fruit.

The post-optimum period occurs at the end of the optimum period and lasts around 7 days, depending on the cultivar. The main after-storage defects of fruit picked during this period are low firmness, bruising, yellowing, mealiness and decay. Post-optimum fruit should be allocated for short-term storage due to the higher risk factor than optimum fruit.

It is recommended that cultivars be harvested within 7 - 10 days of the release date, depending on the variety, for long-term CA storage. A further 7 days can be added for short to medium-term CA storage.

The decision whether to harvest an orchard once the release date has been reached, will depend on many factors, notably fruit size and colour, storage potential, marketing requirements and last but not least, the cultivar mix and the infrastructure available to accommodate the fruit within the required time frame. The purpose of maturity indexing is to ensure the best quality fruit for marketing after storage. This point is often missed by growers in their quest for the ideal colour and fruit size specification.

The following tables list the maturity criteria for the harvest window of apples and pears:

MATURITY CRITERIA

Apples	Release Criteria				Over mature Criteria	
	Firmness (kg)	%TSS	Starch (% white)	Acid %	Firmness (kg)	Acid %
Royal Gala	8.4	11.0	15	0.40	5.9	0.35
Golden Delicious	7.8	12.0	15	0.50	5.4	0.40
Red Delicious types	8.0	11.0	10	0.30	5.9	0.25
Braeburn	8.6	11.5	20	0.60	6.3	0.40
Granny Smith	7.8	11.0	20	0.75	5.9	0.55
Fuji	8.5	13.5	20	0.45	5.4	0.35
Cripps' Pink	8.7	12.5	10	0.75	6.3	0.55
Cripps' Red	9.1	12.5	15	0.75	6.3	0.60

Pears	Release Criteria			Over mature Criteria	
	Firmness (kg)	%TSS	Acid %	Firmness (kg)	Acid %
Williams Bon Chrétien	10.5	11	0.35	7.2	0.30
Beurre Hardy	6.4	11	0.45	4.1	0.35
Beurre Bosc	8.1	12.5	0.30	4.5	0.20
Doyenne du Comice	6.8	12.0	0.35	3.6	0.25
Packham's Triumph	8.0	11.5	0.30	5.0	0.20
Forelle	6.8	13.5	0.30	4.5	0.20

Table 11

COMMERCIAL SELECTION OF FRUIT FOR LONG-TERM STORAGE

Fruitlet analysis

Fruitlet analysis samples on apples are conducted around 62 days DAFB. These results can be used to determine the number of calcium sprays per orchard. Granny Smith which is not as susceptible to bitter pit and which has a long storage life, is usually given six calcium sprays whereas Golden Delicious, Braeburn and the red cultivars may require eight to ten sprays.

Fruit analysis

Fruit analysis of apples commences two weeks prior to the first expected picking date of a cultivar. For optimum quality fruit in CA stores, the best orchards can be selected on the basis of mineral content and various mineral ratios. The calcium content of fruit improves storage potential and decreases the risk of decay. It is advised to use a service provider or consultant for the purpose of ranking orchards according to storage potential.

In addition to the mineral content, take cosmetic appearance, fruit size and colour into account, as evaluated on the tree. The selected orchards should be discussed with the production manager on the farm to obtain his inputs. Any irregularities in terms of growth, pruning, chemical and/or hand thinning, irrigation, fertilisation and pest management should be considered. If any of the above has been detrimental to storage potential, the orchard should not be selected for CA.

At harvest

Concentrate on harvesting orchards designated for long-term storage within 4 - 7 days after the orchard has been released for picking. Thereafter focus on orchards allocated for medium and short-term CA storage. The fruit must be cooled according to the prescribed CA standards.

It is important to match the appropriate storage/market strategy with appropriate harvest maturity to provide fruit to consumers with acceptable eating quality throughout the marketing period.

MONITORING OF FRUIT QUALITY

Monitoring the quality of the fruit in the different CA rooms helps the marketing manager to schedule his programme in such a way that he will sell quality fruit throughout the required marketing period.

Prior to sealing a CA room, a composite sample can be drawn from a bin/orchard/room and samples of twenty fruit can be placed in netlon bags and stored either near the door, or on the top bins under the hatch in the CA room's ceiling.

Maturity and shelf-life tests should be conducted on a monthly basis. Special care must be taken to note any signs of mealiness, internal breakdown, scald development, core flush (Granny Smith) and decay.

CHAPTER 11

OPERATION OF CA STORES

A. BASIC GUIDE-LINES FOR OPERATION OF CA STORES

P. Steynor

COLD STORE CONSTRUCTION AND CONTROLS

Each cold store is gas-tight and pressure-tested for tightness before commissioning. Each store is equipped with a sliding door with a personnel hatch, a roof hatch, cooler inspection windows, and pressure relief box. The refrigeration control system incorporates an electronic temperature control of the air temperature entering the fruit stack, with a digital temperature display. The set point is adjusted within the controller and displayed by pushing the set point push-button. A four-position selector switch is provided for refrigeration and defrost control: *Defrost, Manual,* Off, *Automatic.*

In **Defrost**, the defrost circuits are energised. After a visual inspection of the coolers when defrost is complete, return the selector to Manual.

In **Manual**, no defrost occurs at all, but the room temperature is maintained automatically.

In **Off** all refrigeration circuits are de-energised.

In **Automatic,** room temperature control is automatic and defrost is controlled through a 24 hour time clock so that defrost occurs at pre-set times and is terminated automatically.

Each store is provided with a temperature data-logger having measuring points for air supply to the fruit stack, and air leaving the fruit stack and two fruit probes for measuring fruit temperatures close to the door and at fruit below the coolers. Each store is provided with lights for use during loading and for inspection of fruit as well as maintenance lights for inspection of coolers.

LOADING OF FRUIT INTO STORE

Rate of loading

Fruit for CA storage should be loaded into the store as quickly as it is available, so that the room can be closed and the atmosphere established.

Defrosting during loading may be required two or even three times per day but this frequency reduces quickly after all fruit is cold and reduces even further once the room temperature and humidity is stabilised.

Bin stacking pattern

The stores are designed for block stacking of fruit in bulk bins. In general, fruit is loaded ex-orchard without pre-cooling elsewhere. Normally, one cultivar only is loaded into a store although mixes are sometimes selected, depending on marketing requirements. Only cultivars requiring the same gas and temperature regimes should be stored together.

Bins should be block stacked with the first row against the curtain under the coolers, approximately 600 mm from the back wall of the cold store. Stacks should be side shifted tight together and normal design will allow a gap on one side of the room of 200-300 mm with 400-500 mm on the other side. This allows access to the front of the stack during loading for positioning of fruit temperature probes.

The first two rows under the coolers are designed to be stacked nine bins high with subsequent rows stacked ten bins high. Rows should be stacked hard up against the row in front with bin bearers lined up forming an air slot through the length of the stack. There is space for two rows of bins nine-high and eleven rows of bins ten-high, leaving a space to the front wall of approximately 4 500 mm.

The remaining space is filled with bins turned at 90° allowing air spaces between stacks. Do not block stack the turned bins as this will create hot spots as air is prevented from reaching the front wall of the cold room (Fig. 3). It is especially important to leave the 200 mm gap between the 90° turned bins and the main stack.

OPERATION AS A RA STORE

If the store is to be operated as a RA store, the main block of bins can be loaded but it is not recommended that the turned bins near the door are loaded except in exceptional circumstances. Defrosting under RA conditions is carried out with the room selector in **Automatic** with either one or two defrosts per day set on the 24 hour time clock.

Important: If the room is to be operated as a RA store, it is recommended that the roof hatch is not completely sealed, by propping it partly open. This will prevent excessive pressures developing during rapid changes in temperature and during defrost. Operate the store with no water in the pressure relief box.

OPERATION AS A CA STORE

Safety Equipment

As described in chapter 9.

Storage at 0% CO_2 (See Chapter 7 for full details)

For fruit cultivars requiring 0% CO_2 during storage, lime bags should be added during loading. This is most conveniently arranged by spreading lime bags on pallets on top of the bin stack. Total lime bag requirement is normally 1 x 12,5 kg bag/bin. The balance of lime can be made up by stacking bags in bins immediately inside the cold room door.

Storage with CO_2 Control

CO_2 control will either be conducted by activated carbon scrubbers or lime. If lime is used, leave space at the door for fitting of an internal lime tent. As soon as the room is full, fit the lime tent and check its fan operation. Thereafter, fit the door angle iron against the floor angle iron and close the door after applying petroleum jelly to the door gasket. Clamp the door down with the six cam clamps and check that the seal is seating correctly. Leave the store through the, hatch, grease the gasket and clamp the hatch closed.

Flushing with N_2 (See Chapter 7 for full details)

N_2 from a road tanker with vaporiser is introduced through the lower connection on the front wall.

Important: Leave the roof hatch open to avoid over-pressurising the room.

Sealing

On completion of flushing, seal the roof hatch and the residual O_2 will then be consumed through respiration of the fruit.

Establishing of final O_2 levels

O_2 reduction of 1% per day is normal although this is dependent upon fruit temperature at time of closing.

GAS MONITORING EQUIPMENT (See Chapter 7 for full details)

A manually operated system is provided for measuring O_2 and CO_2 levels in each store with samples drawn through a 6 mm line to the central monitoring position in the control room.

To check on calibration of gas monitoring instruments, a bottle of known gas concentration is required. This should contain a mixture of approximately 95% N_2 and 5% CO_2 or 95% N_2 2,5% O_2 and 2,5% CO_2. The bottle must be supplied with a composition certificate and should be fitted with a low pressure regulator piped to the monitoring equipment. Check the calibration and span of the monitor by checking against the known gas bottle and against fresh air.

TO MAINTAIN O_2 LEVEL (See Chapter 7 for full details)

Due to respiration, the 0_2 level in the store will reduce below the required level. Open the 75 mm diameter PVC connection to allow O_2 levels to increase. Time and amount of opening requires experience, but this is gained quite quickly.

If the O_2 level persists above the required level, air is leaking into the store and the most probable causes are: door seal, hatch seals, pressure relief box.

CONTROL OF CO_2 (See Chapter 7 for full details)

The CO_2 level will initially be close to zero but will rise as fruit respires. Operation of the scrubber or lime tent fan for a variable time will control CO_2 at the required level. The fan running time is dependent on the amount and freshness of lime and required CO_2 level. Once the level continues to rise with the fan operating full time, the lime requires changing.

GAS MONITORING AND RECORD KEEPING

A standard log sheet (see Appendix 3, Chapter 6) is used, requiring **O_2, CO_2** and **temperature** recording at least once per day. Recording twice per day is however, recommended. Check the gas monitor calibration daily until confidence is established.

DEFROSTING A CA STORE

Defrosting is infrequently required under CA conditions and is normally carried out under supervision.

Select **Defrost** and open the 75 mm PVC connection to minimise pressure changes in the store. Check removal of all ice from the cooler visually and on completion of defrost, return to manual. Close the vent pipe.

Requirements for defrosting may be indicated by a rise in the ampere readings of the fans and also by a rise in temperature change between fruit at the rear and front of the stack.

On completion of defrosting, precautions to prevent sudden large pressure changes in the room must be observed.

UNLOADING A CA STORE

Allow 24 hours to vent to normal atmosphere by opening the roof and door hatches. Check that the O_2 content is 21% before entering.

B. USEFUL HINTS ON STARTING UP A CA STORE

J S Findlay

1. One month to 2 weeks prior to starting refrigeration, check the gas tightness of all the stores. It is impossible to check if there is any refrigeration running in any of the adjacent stores.

   Use an ordinary vacuum cleaner with a manometer using either a positive or negative pressure of 30 mm of water gauge, NOT MORE. This must hold for 30 minutes down to 20 mm. Some operators prefer a pressure of 26 mm of water gauge which must not drop more than 5 mm over 30 minutes for a really gas-tight store. If there are any gas leaks, it is easier to detect and repair such leaks with a negative pressure, with someone inside the store, checking with soap and water.

2. One to 2 weeks prior to starting refrigeration, check the thermometers and temperature probes and calibrate them, using a bucket of water with floating crushed ice at O°C or a known electrical resistance.   14.

3. The lime tent must be checked, as well as the operation of the small fan on the lime tent.

4. Order sufficient lime for the next 1 to 2 months. The CA industry uses a 12,5 kg bag of $Ca(OH)_2$. The normal annual consumption of lime is approximately 1 bag per bin for 6 to 8 months storage, possibly slightly more for Granny Smith and less for other cultivars.

5. A lime tent normally takes 60 bags of lime on pallets with dunnage to separate the bags so that the CO_2 can get to the lime in the tent, just inside the door. These 60 bags should last between 3 and 6 weeks, depending upon the respiration rate of the fruit inside the store. Alternatively, CA complexes use activated carbon scrubbers instead of lime, as they are more efficient and cleaner. This is dealt with under CO_2 scrubbing in Chapter 7.

6. Arrange for the flushing of the CA stores with the suppliers of liquid N_2. Consumption of liquid N_2 is approximately 1 kg/bin down to 7% to 8% O_2; 1,5 kg/bin down to 5% to 6% O_2 2 and 2 kg/bin down to 4% to 5%. It is important to have a large enough hole to discharge the gas otherwise the walls of the CA stores will collapse. A trap door left open in the roof of the store is probably the best method, but must be properly sealed as soon as flushing is complete and the pressure has reached equilibrium. A CA store is normally flushed with a positive pressure of 10 mm of water gauge. Place a polystyrene pad on the bin opposite the liquid N_2 discharge, or use a distribution pipe, to prevent any freezing damage in that bin.

7. Refrigeration should be started 2 days prior to loading and the store brought down to temperature. All refrigeration equipment, instruments and valves and the defrost system must be checked. Make sure the re-starting of the refrigeration after defrost is correct, i.e. with a time delay before the fans start so that the refrigeration starts first and the cooling coils come down to room temperature before air movement starts, otherwise a very large pressure change will occur inside the store. It is presumed that the annual maintenance of valves and strainers has been done in the off season.

8. Gas instrumentation must be checked against a bottle of gas with known concentration which can be purchased from a supplier of special gases.

9. Load the stores at the designed loading rate, checking the air flow and the curtaining.

10. When full, seal the rooms and flush with N_2 preferably with the last fruit loaded at + 2°C to + 3°C which assists in bringing the O_2, down to 1,5% O_2.

11. Until familiar with the room and CA storage, do not allow gas concentration to drop below 1,5% O_2.

12. During the first year of operation, a visit to an experienced operator nearby would be worthwhile.

13. Remember that gas concentrations inside the CA store are lethal and can kill within 45 seconds. If, for any reason, it is necessary to enter a CA store in operation, the correct safety procedures as laid down by the PPECB & Department of Manpower, detailed in chapter 11, should be strictly adhered to. If any repairs need to be done, bring the gas concentration back to 21% O_2 before entering.

14. Enough samples, to be withdrawn monthly, should be placed in netlon bags (not plastic unless they have large holes in them) so that they can be hooked from the store with a pole, possibly in an empty bin below the roof hatch. Again, do not breathe the atmosphere right next to the opened hatch.

The best advice about entering a CA store is, don't.

C. PRACTICAL MANAGEMENT OF COLD STORES

P. C. van Bodegom

NEW FACILITIES OR EXTENSIONS

Cold storage of deciduous fruit is a specialised field nowadays. It is advisable to do a proper investigation before it is decided what type and size of facility is needed for your specific circumstances. It is also advisable to involve consultants in cold storage projects, as mistakes made in this field are not easily corrected and are very costly. A few other points that should definitely be looked at carefully are:

1. Type of structure, including covered loading areas.
2. Capacity of the refrigeration plant, which depends on your planned intake capacity on a daily basis.
3. Make provision for future extensions or upgrading of your facilities on the side of electrical power supply and refrigeration plant. In many instances this will prevent costly alterations in the future.

PREPARATION OF A COLD STORE BEFORE STARTING UP

Cleaning

It is absolutely essential that a cold store used for the storage of fresh produce, must be cleaned before it is started up. Even if the same type of produce is stored, this cold store should be cleaned at least once a year or more often if circumstances warrant it. The entire cold store should be washed thoroughly and thereafter disinfected with a flowable fungicide.

Lighting

Adequate lighting spread evenly over the cold store area is most important. (The specifications for light intensities are laid down in the Regulations of the Occupational Health and Safety Act.)

Normally metal halide lamps or high-pressure mercury vapour lamps are used in our type of cold stores. These lamps give a high light output combined with a long lifetime.

General maintenance points

Some general points that should be attended to on a regular basis and certainly before start-up:

1. Testing of drain line and defrost pan heaters.
2. Cleaning out of defrost drain lines including their water traps as accumulation of dirt takes place through the year in these lines and this can cause spillage of defrost water from the cooling coils onto your products in the cold stores.
3. Doors to be checked for proper sealing against the door frames (sealing rubbers wear out) and also the proper working of the safety lock to open the locked cold store door from the inside of the cold store, in case somebody is trapped inside.
4. A calibrated mercury or spirit thermometer to be placed in the air stream from the coolers.

Floor plans

It is most important to make use of your available floor space to its maximum capacity. Work out a floor plan that will suit your own type of operation. Always keep in mind that you must have sufficient air flow to keep your products cold under all circumstances. Use road line paint to mark out floor lines for different stacking methods. White and yellow painted lines on the same cold store floor can successfully be used, where the one colour is for apple carton re-cooling and storage and the other colour for the storage of products in bulk bins.

OPERATION OF A COLD STORE

Cold storage & proper handling ensures maintenance of fruit quality. Slow cooling, fluctuating temperatures and fluctuating gas regimes will reduce most of the benefits of cold storage.

Starting up

Start up 2 - 3 days before you want to commence loading, as it takes a few days before the whole structure, including the floor, comes down to the required storage temperature. During this time, set the controls at the correct setting for the required temperature. Test your low temperature safety control and alarm. Check your continuous recorder readings against the readings of a calibrated thermometer inside the cold store. Remember, if you store a variety of products, to bring the temperature down as low as possible without doing any harm to the product with the highest storage temperature.

LOADING OF A COLD STORE

Check what the daily intake capacity of a cold store is and do not overload a cold store, as the result will be detrimental to the stored produce. Use electric forklifts whenever possible. If an internal combustion type of forklift is used, install an Engelhard gas purifier to eliminate carbon monoxide (CO).

Give your forklift drivers proper training, supply adequate protective clothing and use your most senior and reliable drivers to operate forklifts in cold stores. It is advisable to have cold storage drivers on a higher wage scale as this type of work is more difficult and is sometimes done under sub-zero temperatures with a wind chill factor.

TEMPERATURE MANAGEMENT AND CONTROL

Temperature control is done by thermostats with a narrow differential or with more advanced electronic controls, where a motorised valve is controlled over a 0 - 100% span. Close temperature control is also beneficial to the fruit and variation of fruit temperature through the room must be kept to an absolute minimum of 0,5 - 1°C.

For temperature measurement each cold store must be equipped with a continuous temperature recorder, a calibrated thermometer inside the store and if possible, a remote electronic thermometer. The latter could also be part of a central electronic control and management system.

When heavy loading takes place during certain times of the day, check the cooling coils regularly for ice build-up. You may have to defrost more often otherwise you will lose cooling capacity.

If, for practical reasons, the doors of the cold store are open continuously over long periods, install a plastic curtain in the door opening to prevent cold air going out or warm air coming into the cold store. Daily fruit core temperatures must be taken by the plant operator and recorded in a register or logbook.

REFRIGERATION PLANT AND RECORD KEEPING

Most of our plants use either freon or ammonia as a refrigerant.

Freon

Advantage:
It is a non-toxic, safe gas which does not smell.

Disadvantages:
Leaks are difficult to detect as it does not smell. Heat transfer capacity less than ammonia, resulting in more power consumption for the same refrigeration capacity. Freon is ozone-unfriendly and is being phased out in South Africa due to the signing of the Montreal Protocol.

Existing installations must replace Freon with another approved refrigerant.

Ammonia

Advantages:
Greater heat transfer capacity and leaks are easily detected.

Disadvantages:
It is a dangerous gas, toxic and explosive in high concentrations.

Operation of ammonia plants must be monitored at least twice a day and provision must be made for night-time and weekends in such a way that somebody can give immediate attention to problems arising.

Run the refrigeration plant on a continuous basis, try to prevent STOP-START situations as far as possible. A continuous operation cycle will normally result in:

1. Lower maximum demand from the electrical supply system, resulting in savings on electricity bills.

2. More important is that a stable suction pressure will result in a more stable air temperature in the cold store. This will result in less moisture loss in the fruit over longer storage periods due to a higher relative humidity caused by lower temperature difference between the coolant and the air in the store.

MAINTENANCE

Daily checks must be made on standard items, e.g. oil levels, oil consumption, drainage of oil back out of the system, refrigerant levels, V-belt drives, etc.

If possible, get a full set of instruction books and operating manuals and work according to these instructions. One must remember that most of this machinery is imported and often parts are not available on short notice. **Prevention is better than cure** is certainly applicable in this case and therefore one should practice preventative maintenance.

RECORDS

By law it is required to keep a Refrigeration Record Book which must be available for inspection by a Government factory inspector. It is advisable also to keep log sheets or a log book for the daily monitoring of the plant. An example of a log sheet from a log book is included (see Appendix 3, Chapter 6).

CHAPTER 12

HANDLING PROTOCOLS FOR CA STORED FRUIT

J. S. Findlay, P. C. van Bodegom

The reason for cold chain management is to get our products as fresh as possible and of the highest quality to the consumers. The maintenance of the optimum storage temperature during the handling, transport and marketing of perishable produce is referred **to as the cold chain.** For most of the deciduous fruit (including apples and pears) this temperature is -0,5°C. Our farmers are producing fruit of the best quality in the world; pack houses and cold storage operations spend a lot of capital, time and effort to maintain this high quality, but when the fruit is despatched from our cold stores to the local markets and other local buyers, this cold chain is in many instances broken. The result being that fruit and vegetables of the poorest quality can be found in our local retail outlets. Yet we manage to market fruit overseas that is known for its outstanding quality, which is mainly due to the fact that very strict regulations apply and are adhered to for export, preventing the cold chain from being broken. With most of the fruit for the local market being selected at optimum maturity, we are able to also supply our local consumers with a high quality product, as long as we maintain the cold chain properly.

The management and maintenance of the cold chain plays a vital role in the quest for optimum quality, particularly in the municipal market distribution system. A positive attempt was needed to find solutions for those nagging, recurring problems which hamper effective handling and distribution of apples and pears and to set ideal standards which would cater for their specific needs.

As a result a Cold Chain Code of Practice was drawn up for the deciduous fruit distribution chain.

The cold chain is a demanding and complex operation. (Fig. 8). The very high value per ton and total turnover of apples and pears is an indication of the need for an economical and effective cold chain to ensure that fruit which leaves the producer is above suspicion.

RECOMMENDED COLD CHAIN CODE OF PRACTICE

1. Harvest according to maturity indexing analyses.

2. Pre-cool all fruit to 0°C within 48 hours of harvest.

3. Prepare marketing plans and hold all fruit at -0,5°C, only within pre-determined maximum periods of storage inclusive of marketing process related to specific conditions of fruit lots.

4. Pack consignments for market and re-cool fruit to 0°C within 48 hours.

5. Prepare specific consignments for marketing within the cold stores at 0°C.

6. Load refrigerated transport vehicle at 0 'C with minimum temperature gain.

7. Vehicle must travel with air temperature of not above 4°C and not below 0°C. Fruit temperature must not exceed 4°C on arrival.

8. Control of fruit in cold stores:

    i) **Short-term storage for sale within (say) 10-14 days:**
    Fruit to be received at no higher than 4°C and this temperature not to be exceeded during the storage period.
    Air temperature off the coolers should never exceed -0,5`C.

ii) **Longer term storage (say 2-15 weeks):**

Fruit to have been pre-cooled to -0,5°C at time of harvest and to have been despatched at -0,5°C. Fruit to be received not above 6°C and to be re-cooled within 48 hours and thereafter to be maintained between -0,5°C and 0°C.

13. Palletisation

i) The export norm of seven-cartons high is required for standardisation for both transport and cold storage.

ii) With flatbed trucks, improved temperature conditions could be obtained with insulated tarpaulins.

iii) the following procedures should be adopted in cold stores:

Cold stores should be standardised to receive seven-carton high pallets stacked one, two or three-high with either pallet racking and pallet stacking irons (racking being preferred).

METHODS FOR MAINTAINING NORMS IN COLD CHAIN MANAGEMENT

Immediate pre-cooling after harvest.

Fruit put into cold store does not get cold by itself, whether in bulk bins or a packed carton. The cartons and/or bins must be stacked in such a way, so that the cold air passes through or is forced through the fruit in the container itself.

The following cooling methods can be used to achieve this:

a) Curtains with bin in return airflow

b) Serpentine cooling in bulk bins

c) Sideways pressure drop cooling in bulk bins

d) Single row tunnel cooling, either with mobile fans or static fixed fans.

Keeping the fruit cold while packing

a) Shortest possible time from bulk bin in pre-cooling chamber to carton in re-cooling chamber.
b) Water for bin dumping and conveying fruit to be as cold as possible.
c) Fruit exposed to ambient temperature for as short a time as possible and not left around on circular packing tables over tea breaks.
d) Carton lidded as quickly as possible.
e) Cartons palletised and returned to cold store as quickly as possible, otherwise a large amount of energy is wasted in the re-cooling process.

Re-cooling after packing

a) Difficulty in removing the last 3 to 4°C from an insulated carton, especially when a polyethylene bag is used.
b) Pressure drop single row tunnel cooling, closing all air short circuits with light-weight plastic, is the only method by which this can be accomplished with a 100% success.

Refrigerated transport to the retailer and keeping fruit cold until it is bought by the consumer

a) The longer the fruit is held at the optimum storage temperature prior to being bought by the consumer, the longer that fruit will stay fresh and crisp.
b) Every one degree increase in fruit temperature shortens the time that the retailer has to sell a crisp and fresh fruit.
c) If fruit gains temperature in transit, it should be re-cooled on arriving at the retailer.

Quality loss if these norms are not maintained

Any fruit held at a temperature higher than optimal storage temperature for that particular fruit, will lose quality. The higher the temperature, the faster the quality loss.

a) Bon Chretien pears will ripen and develop senescent scald and fungal rots.
b) Packman's Triumph will soften and develop fungal rots.
c) Golden Delicious will turn yellow, go mealy and develop soft scald.
d) Starking will go mealy very quickly.
c) Granny Smith will turn yellow, soften and go waxy.
f) Senescence in all deciduous fruit is a function of time and temperature. The longer the time after harvest, the better the cold chain management must be.

METHODS OF MAINTAINING THE HIGHEST QUALITY OF FRUIT

IMMEDIATE PRE-COOLING AFTER HARVEST

By just placing fruit into a cold store, it will NOT come down to the correct storage temperature in time to maintain good quality.

Bulk bins or other containers in which the fruit is placed after harvest must be stacked in such a way that the air is FORCED through the fruit in the container itself.

By just stacking rows of warm fruit in the direction of the air flow, it will take a very long time before the fruit gets down to its required storage temperature, resulting in a loss of quality of the fruit.

A better way of stacking is directly across the air flow in the cold store (like a curtain). In this way, by using the full width of the cold store, the air cannot bypass the fruit and is forced to come in direct contact with the fruit in the ventilated storage containers or bulk bins.

A few other methods that are used are the following:

Serpentine cooling (Fig. 9)

a) **Fig. 9** shows bulk bins stacked against a fixed double wall. In the front the 2nd and 4th slots in these bulk bins are blanked off, whilst on the side of the wall the 1st and 3rd slots are blanked off and openings in the wall are provided for the 2nd and 4th bulk bin slots. A powerful fan creates an air flow via the double wall air plenum as indicated by the arrows. In this way all the fruit is in direct contact with the air and cooling takes place very rapidly. When the fruit is cold it has to be placed in a normal holding store for further storage or it has to go to the packing plant immediately in order to allow the next consignment of warm fruit to be pre-cooled.

b) **Fig. 10** shows the same method, but with a mobile pre-cooling fan in front of stack of bulk bins in a normal cold store. The advantage of this method is that no double handling of the fruit is needed. Once this fruit is at the correct storage temperature, the mobile fan unit is moved to another position and not the fruit.

Sideways pressure-drop cooling in bulk bins

This is shown in **Fig. 11**

These two-way entry bulk bins are stacked in rows with a gap in the middle. A tarpaulin is placed over the top, hanging down in the front and at the back, in this way making the gap into an air plenum. A mobile fan is placed in the front and any other openings in the front and at the back are closed. When the fan is started, a pressure drop in the air plenum results in the cold air in the cold store being forced through the ventilated sides of the bins, in this way cooling the fruit and the warmer air being disposed of via the mobile fan back to the coolers.

MINIMUM HEAT GAIN WHILST PACKING THE FRUIT FOR TRANSPORT TO THE RETAILER

a) Keep the time that the fruit is transferred from the bulk bin via the packing plant to the carton, to an absolute minimum.

An ideal but highly capital intensive example is a packing plant in the USA, where the dumping operation takes place in a cold store from where the fruit is conveyed into the packing station. The packed cartons are immediately conveyed back into a cold store where palletising takes place. In this way the time that the cold chain is broken, and a resultant rise in fruit temperature, is kept to an absolute minimum.

b) Do not allow accumulation of bulk bins or cartons on the pack shed floor.

c) Make and keep water for bin dumping and conveying purposes as cold as possible in order to have a minimum temperature rise of the fruit.

d) Supply packing tables with just enough fruit; no unnecessary accumulation of fruit is permitted.

e) Dumping stations and packing tables to be emptied as far as practically possible over lunchtimes and tea-breaks.

f) If possible, avoid direct sunlight and always handle fruit in shaded areas.

RE-COOLING AFTER PACKING AND THE DIFFICULTIES OF COOLING PALLETISED FRUIT

Under our circumstances we aim at a fruit temperature of -0,5°C with a minimum air temperature of -1,5°C. As this temperature difference (TD) between the air and the fruit is only 1°C, it will be understood that the last few degrees of getting the fruit temperature in a packed carton down again is the most difficult part. For this reason it is generally accepted nowadays that in order to bring the temperature of packed fruit down again, forced air re-cooling is the only acceptable method.

This re-cooling can be divided into two categories:

a) **Convection cooling**, where the air can come into direct contact with the fruit inside the carton as it is forced through the carton.

b) **Contact cooling:** In the case of pears and Golden Delicious apples, the fruit is inside a polyethylene bag inside the carton and the only way cooling can take place is by means of contact with the cold air around these cartons. The result is that this contact cooling is much slower than convection cooling.

A test done by Ceres Fruit Growers on palletised Bon Chretien pears over 48 hours showed the difference between a standard packed pallet and a very well-ventilated pallet (where the cold air could come in contact with more than one side of most cartons) as follows:

	Standard	**Ventilated**
Temperature after 48 hours	3 to 4,5°C	0 to 0,5°C

Pressure Drop Tunnel Cooling (Fig. 12)

The best way of re-cooling packed fruit at this stage is by means of pressure drop tunnel cooling.

This method is done in the same way as described under "Side-ways Pressure-drop Cooling in Bulk Bins". Rows of pallets are stacked in:

Single rows where **contact cooling** has to be done
Double rows where **convection cooling** can be done

The top, front and back of the stack of pallets is again covered with a tarpaulin and all pallet slots around the stack of pallets are also blanked off by means of a thin plastic film, stapled to the pallets. In this way the air is now FORCED through the cartons. This type of cooling is used widely in the deciduous fruit industry and also by the Citrus Exchange in their pre-cooling facilities in Durban harbour.

KEEPING FRUIT COLD UNTIL IT IS TRANSPORTED TO THE RETAILER

After forced air pre-cooling of the packed fruit has taken place, two methods of storage can be followed:

a) Fig. 13 shows a floor plan of a cold store where already pre-cooled cartons are re-stacked into long rows of fruit (space-saving). This is done where we know that fruit has to be kept for some time in cold store.

b) Fig. 14 also shows a few pre-cooling blocks of palletised fruit where No 3 & 4 are already pre-cooled and left in the same position on the floor. This will result in a space loss, but as this fruit is moving out quickly, there is a greater saving when no double handling has to be done in comparison with the space loss over a short period.

Refrigerated Transport

A few points to be mentioned here are:

a) See to it that the truck's refrigeration unit is set at the correct temperature for the produce to be transported.

b) If possible, ask for a continuous temperature recording for the duration of the trip.

c) See to it that the produce to be loaded is at the correct temperature. Remember, the refrigeration unit on the truck is only there to keep your produce at the correct temperature, not to re-cool it to its correct temperature.

NOTE: In the USA, truck drivers refuse loads that are not down to the correct temperature at the time of loading.

d) The loading of the truck must be done in such a way that the cooler unit and its fan can still maintain a sufficient air distribution through the whole load.

e) If mixed loads of product have to be transported, ensure that the correct temperature is used and that these products can safely be transported together without the danger of smells or taints being picked up or ripening processes being accelerated due to the release of certain gases.

KEEPING FRUIT COLD UNTIL IT IS BOUGHT BY THE CONSUMER

Assuming that the fruit arrives at the correct temperature from the producer, then:

a) At wholesaler, distributor and chain store level, ensure that with a minimum of delay this fruit is transferred into a cold store at the correct storage temperature.

b) At retail level look for the minimum amount of fruit on the counters. Temperature rises over longer periods means loss of quality, which in turn means loss of income. One of the answers here is refrigerated cooling counters.

c) Also at retail level, ensure that whatever products are stored together, they are always at the lowest possible temperature and that these products are compatible without any harmful after-effects on other products.

d) Educate the consumer on how to treat fruit once he has bought it (store in refrigerator or cool place); how to prevent fruit from ripening all at the same time, and also how to ripen it for consumption.

QUALITY LOSS IF COLD CHAIN MANAGEMENT IS NOT MAINTAINED

If fruit is stored or transported at a higher temperature than its optimum storage temperature, it will lose quality and shelf-life with every degree higher than its optimum temperature. The higher the temperature, the faster the rate of respiration of the fruit, with the resulting faster loss of quality and shelf-life. Even a break in the cold chain for a period of a few days will reduce storage life and eating quality.

EQUIPMENT, FACILITIES AND INSTRUMENTATION NEEDED TO OPERATE THE COLD CHAIN

For maintaining the cold chain in the deciduous fruit industry, we can divide the cold storage facilities into two categories:

Cold stores in the production areas

These cold stores must be equipped to pre-cool fruit directly after harvesting and to re-cool fruit again after packing. Normal holding storage facilities must also be provided.

Cold stores in the distribution areas

These cold stores must be equipped to hold the incoming fruit at the correct temperature, before it is sold. Due to the fact that a variety of different types of packages and commodities are sometimes stored in the same cold store, a proper air circulation in these stores is important. Also the possibility of venting these stores with fresh air must be considered.

NOTE: It is assumed that all produce arrives at the cold stores in the distribution areas under the correct refrigerated conditions, as would be the case with a normal cold chain that is not broken.

The reason for the above assumption is explained as follows:
If we look at the heat removal, when comparing cooling versus holding of several products, we see that the heat extracting capacity of a refrigeration plant should be up to 100 times more for cooling than holding.

The following examples give the ratio of a few products:

Product	Cooling		Holding
Broccoli	10	:	1
Melons, Carrots	23	:	1
Apples, Oranges, Peaches	45	:	1
Grapes	100	:	1

As in the production areas, everything is cooled down to its correct storage temperature. It does not make sense to spend an enormous amount of capital in the distribution areas to re-cool produce again, because the cold chain has been broken.

Fig. 15 shows a few air circulation systems in cold stores of which in the production areas the false ceiling system (Fig. 15c) is mostly used.

EQUIPMENT AND INSTRUMENTATION

Temperature regulation in cold stores for fruit and vegetables is mostly done as shown schematically in Fig. 16.

Fig. 16a shows one thermostat (T) working a motorised valve (M) for opening and closing the back pressure valve.

Fig. 16b shows the pull down and holding thermostats (T) positioned in the air-stream coming off the cooler. These two thermostats regulate the flow of cooling liquid through the back pressure valve in the suction line, for cooling and holding situations in the cold store.

It is important that the thermostat for temperature control is situated in such a position that the air coming off the cooler is measured. This is done to prevent freezing of produce, through coming into contact with air that might be too cold.

MINIMUM REQUIREMENTS FOR TEMPERATURE MONITORING

For temperature monitoring, a calibrated mercury or spirit thermometer must be installed inside the cold store and a continuous chart recorder (24 hours or 7 days) outside each cold store, both instruments measuring air coming off the cooler.

Daily spot checks in various positions are to be made with an accurate thermometer of the actual produce temperature inside the cold store.

If a warm spot is discovered, check the air flow and stacking pattern and change the stacking if necessary to improve the air flow. These temperatures should be recorded into a log book on a daily basis for future reference.

REQUIRED STORAGE TEMPERATURES FOR VARIOUS PRODUCTS

A list of recommended storage temperatures for various products is discussed in Precooling and Cold-Storage of Perishable Products, INFRUITEC Info No 622, September 1992. Anticipated storage time is important as the longer the storage time, storage temperature becomes vitally important.

SOME DO’s AND DON'Ts IN THE PRECOOLING AND RECOOLING OF FRUIT IN COLD STORES

1. Air management is as important as temperature management in the process of cooling fruit in both cartons and in bins.

1.1. Approximately 750 cfm per pallet of fruit to be cooled or 1250 m^3/h of air is required as a ball-park figure.

1.2. The air must pass through the cartons on the pallet and not by-pass the pallet through gaps in pallet stacks and pallet openings. Cold store plastic is to be used to seal all gaps.

1.3. The pressure drop through the cartons on the pallets must be in the vicinity of 10 mm of water gauge. A simple manometer is essential to determine the pressure drop. Without pressure drop through the cartons, very little, if any, carton cooling is taking place.

1.4. When using a mobile fan (Fig. 12A and 14), the forward velocity of the air in the plenum towards the fan should at no time or place exceed 5 metres per second. Increase in velocity causes the resistance to increase at a square of the velocity; thus air at 5 metres per second loses energy at 1,5 mm of water gauge, whilst air travelling at 20 metres per second will lose 25 mm of water gauge.

1.5. Carton cooling in cold stores with pallets stacked 3-high is very difficult to accomplish especially as the gaps between the pallets are never sealed at this level. In addition, the labour force working under these conditions in sub-zero temperatures with high wind speeds is not very productive.

2. Temperature should at all times be maintained at a level so as not to do damage to the fruit through freezing when cooling. On the other hand, temperature off the coils should not rise above 0°C otherwise the store is being over-loaded and cooling is taking place inadequately. Hot spots in cooling stores should be determined by the operators with as many thermo-couples as possible.

2.1 The return air temperature is equally important to monitor as this indicates how much work the air is doing or how much energy is being wasted.

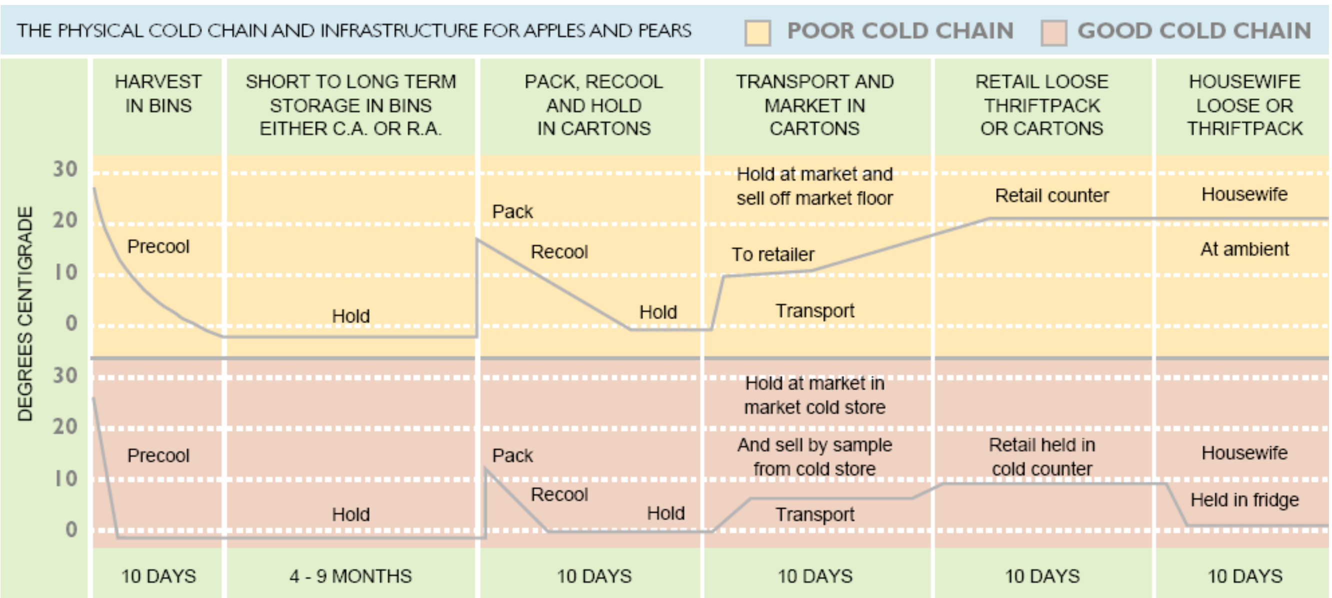


Figure 8. The physical cold chain and infrastructure for apples and pears

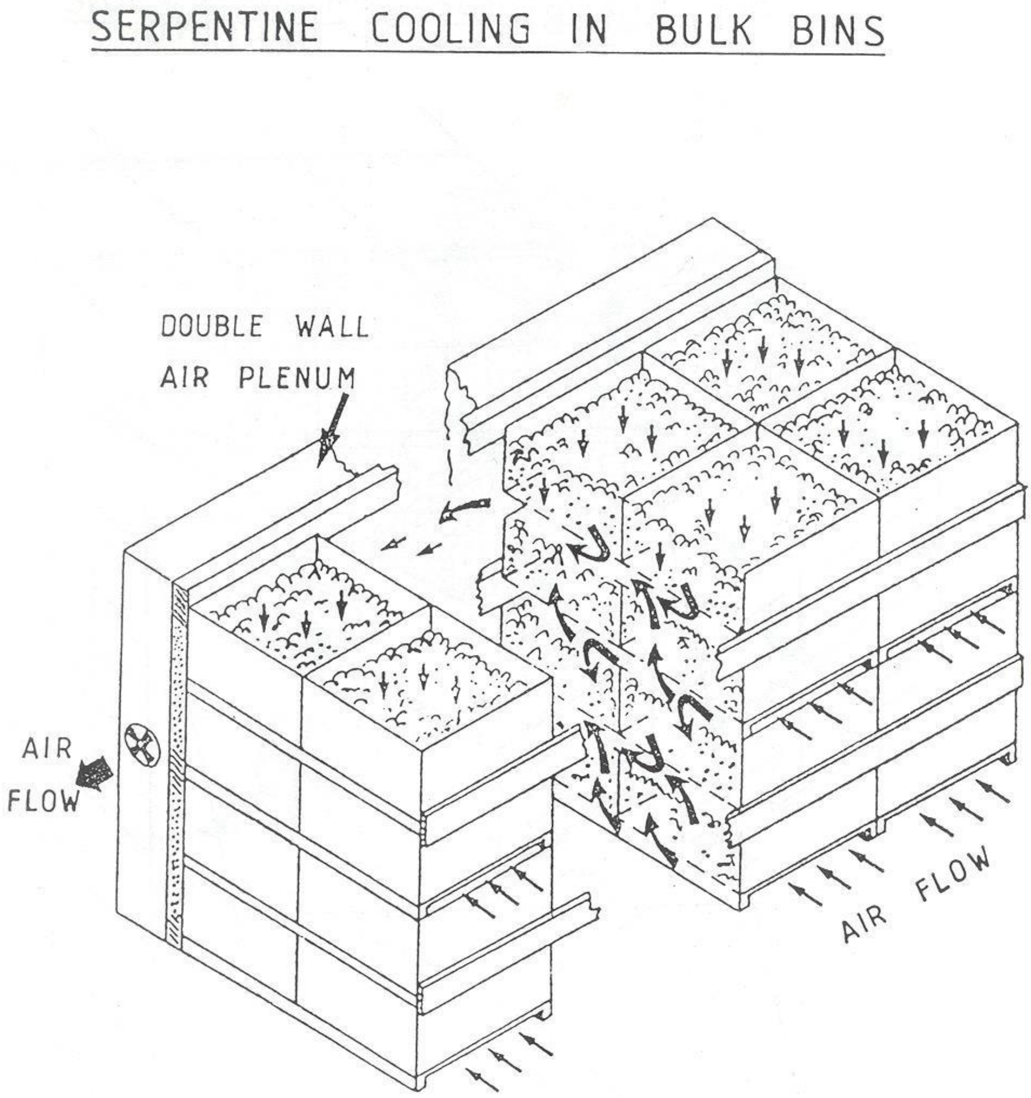


Figure 9. Serpentine cooling in bulk bins

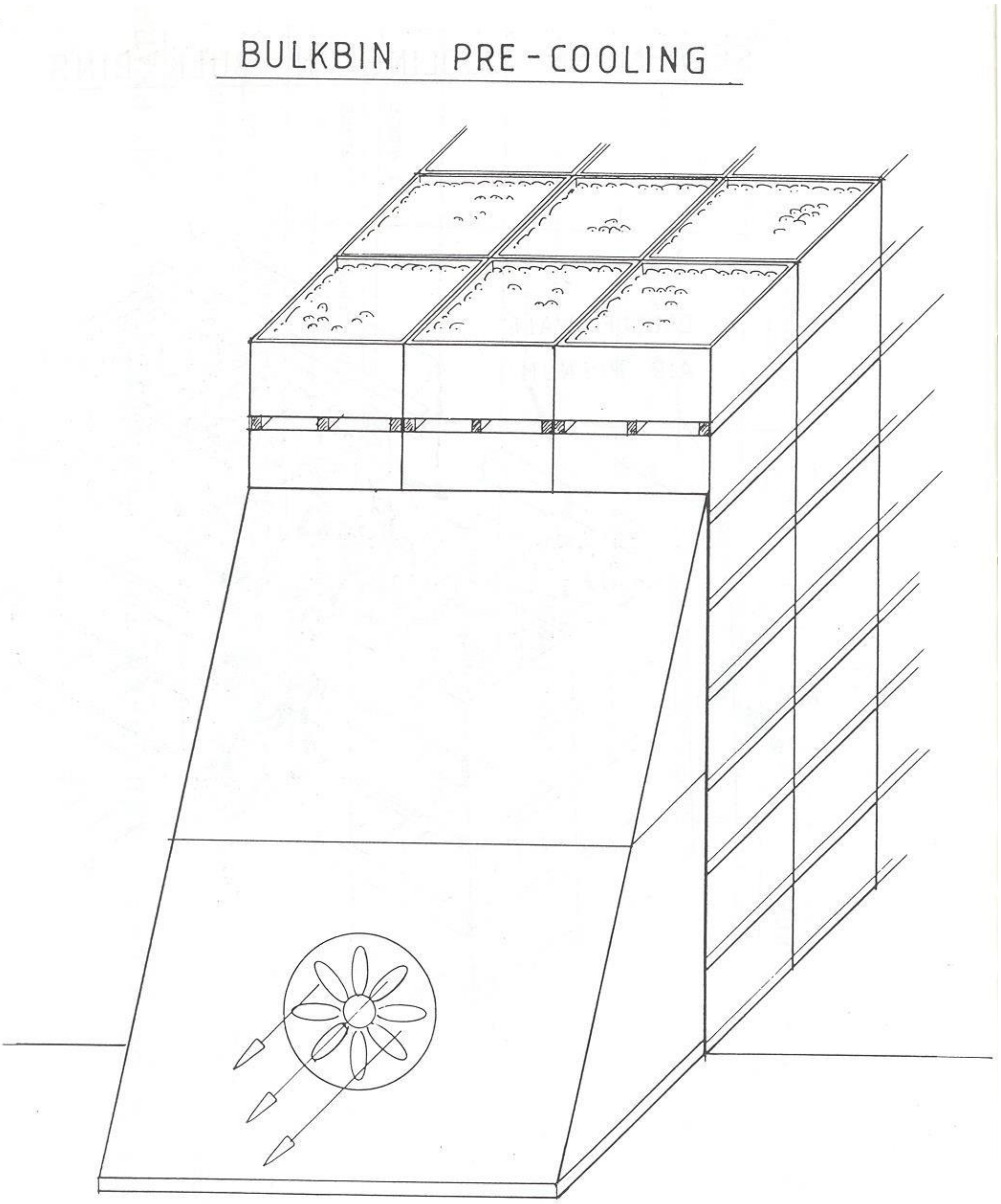


Figure 10. Bulk bin pre-cooling

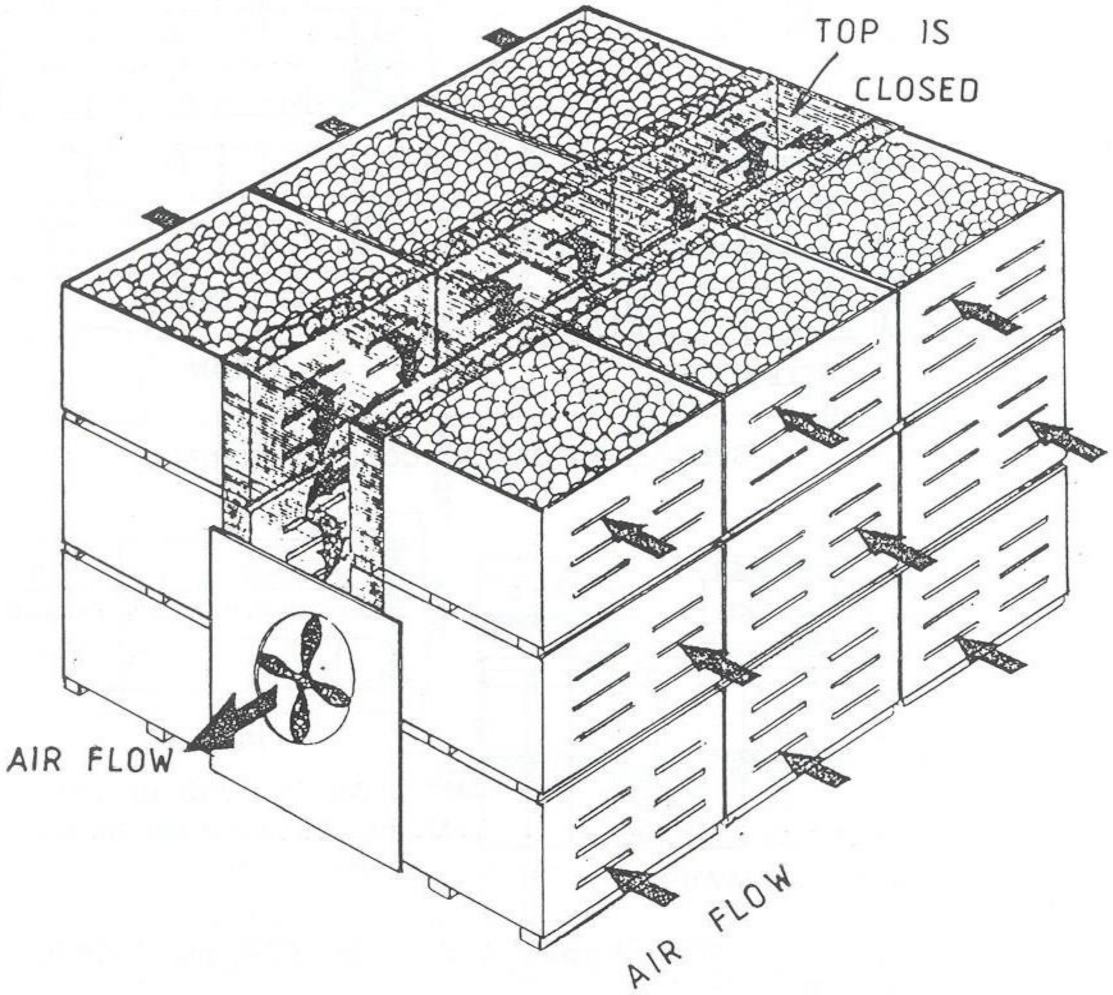


Figure 11. Sideways pressure drop cooling

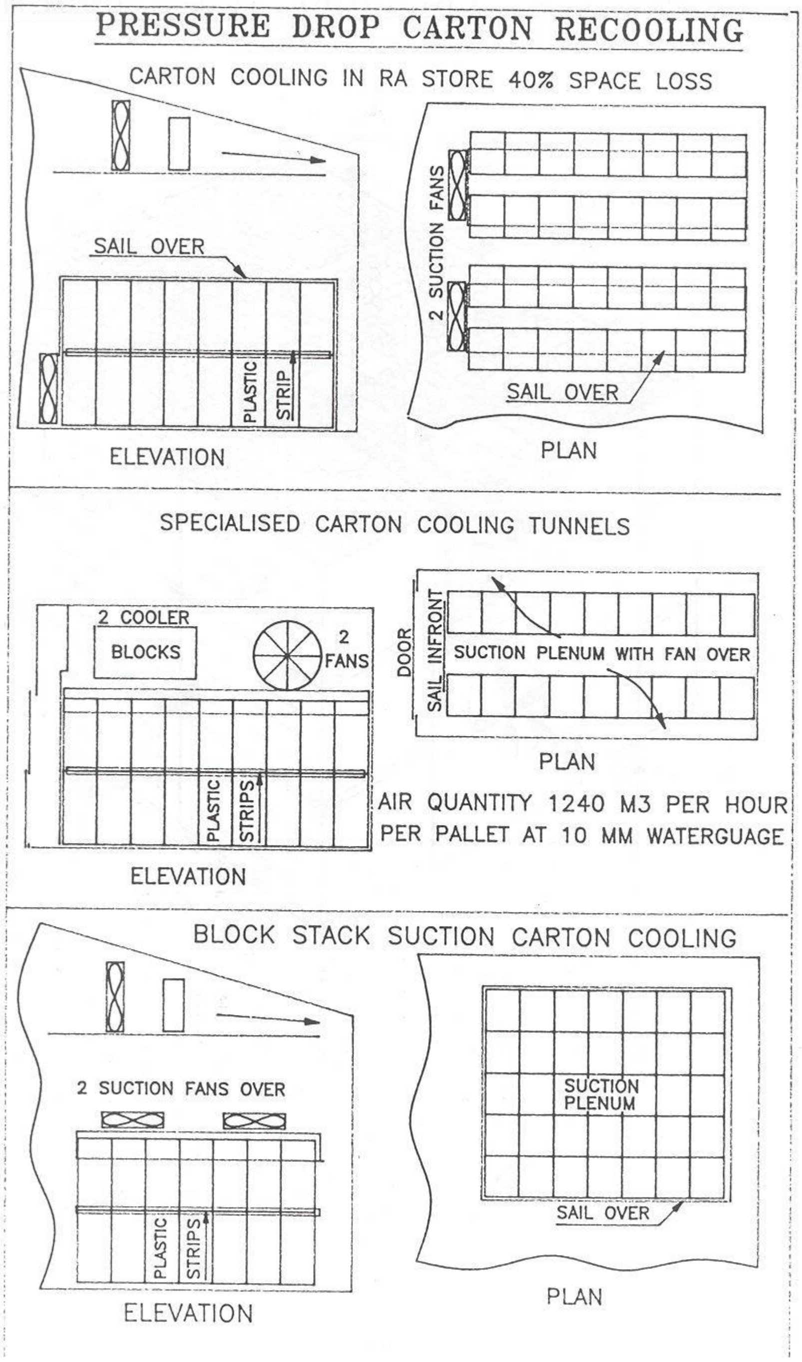


Figure 12. Pressure drop carton re-cooling

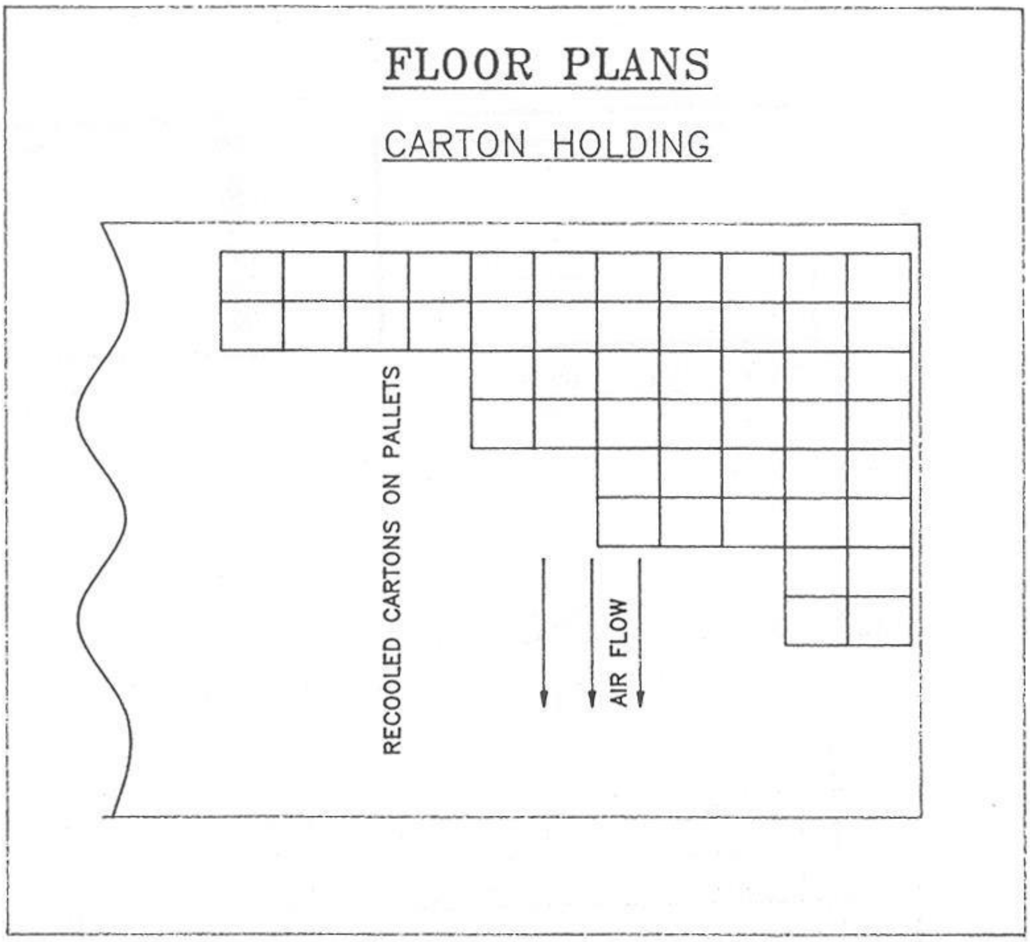


Figure 13: Floor plans

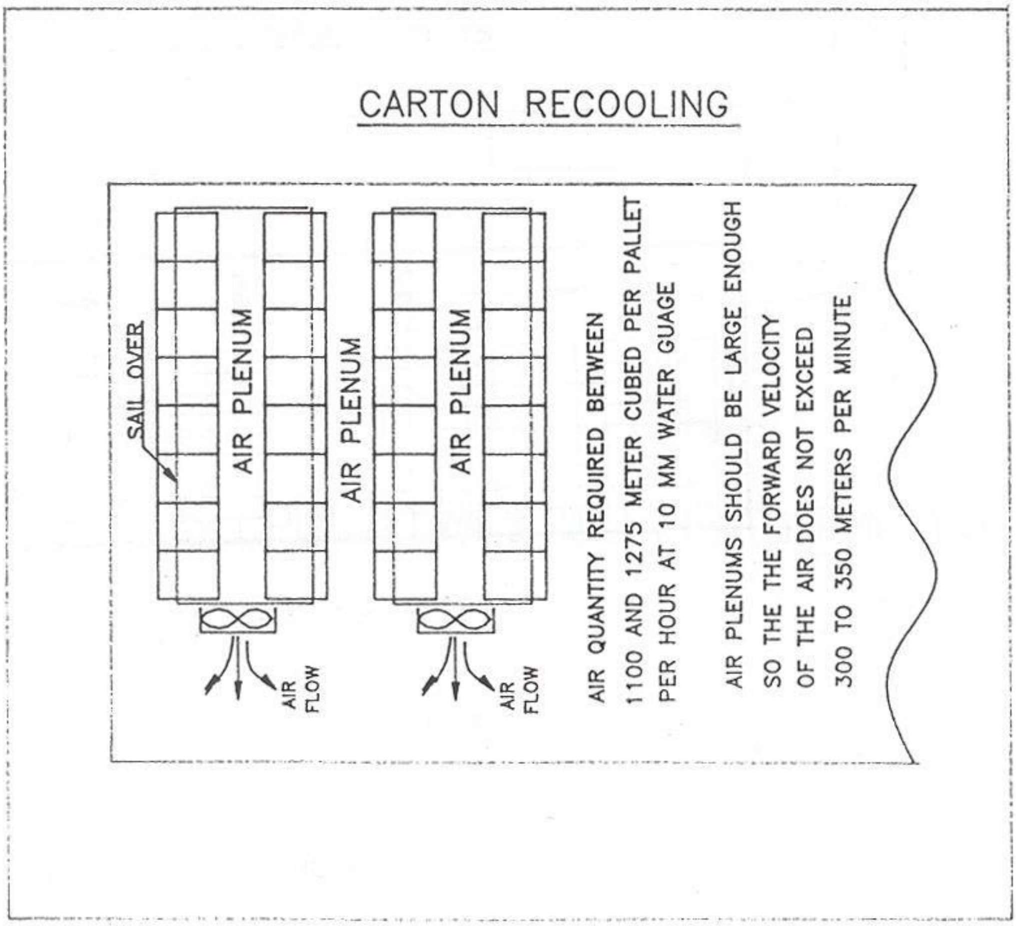


Figure 14: Carton Re-cooling

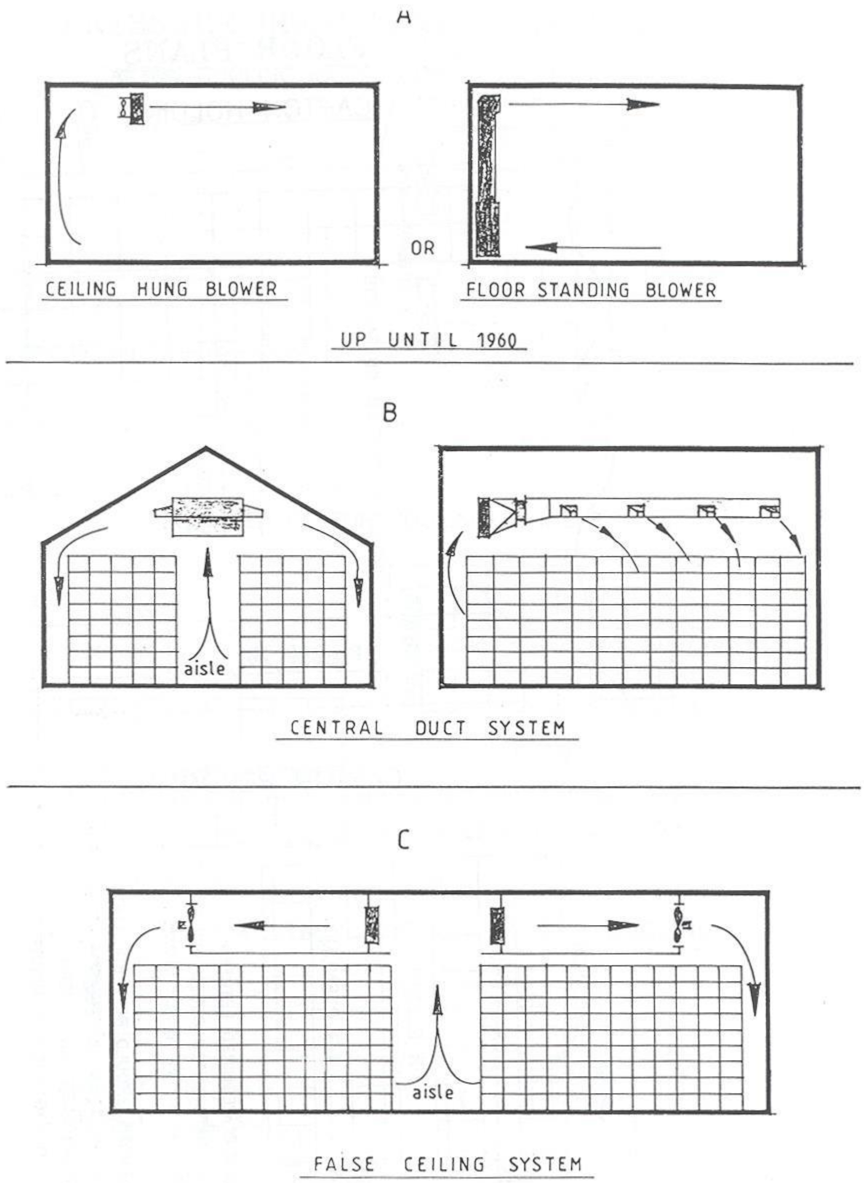
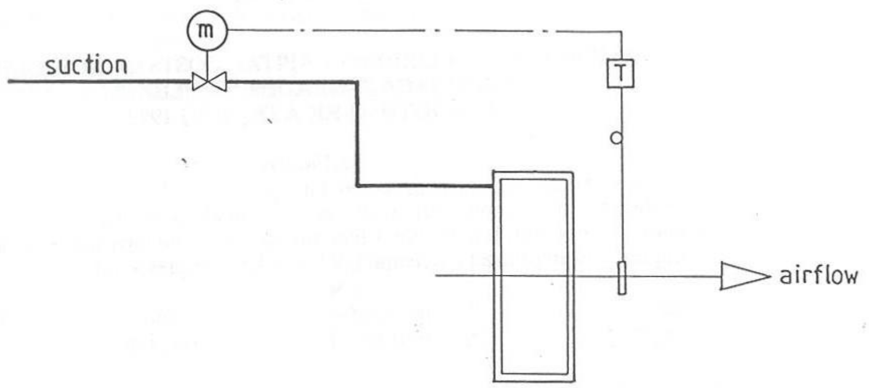
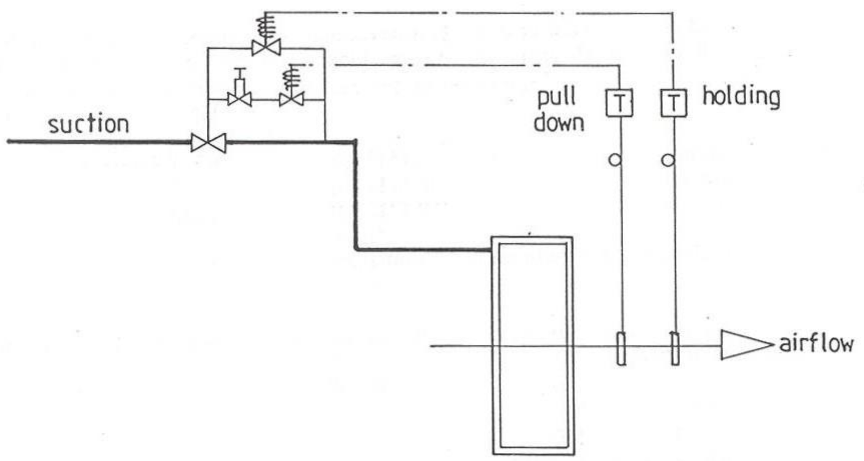


Figure 15: Air circulation systems
A Up until 1960



A THERMOSTAT WORKING MOTORISED VALVE



B PULLDOWN & HOLDING THERMOSTATS

Figure 16 A. Thermostat working motorised valve
Figure 16 B. Pull-down & holding thermostats